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GB 2062857A
GB 2051355A
GB 2044949A
GB 2012949A
US 4117448A
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(54) Remote seismic data system

(57) A fiber optic seismic exploration system includes a plurality of remote data gathering units (132), a recorder takeout unit (134), and a central control unit (140) interconnected with dual fiber cables (20). The cables (20) are terminated at each end with a connector (10) housing a digital, logic compatible transceiver. The digital transceiver includes an optical detector connected to one of the optical fibers and a fiber optic transmitter connected to the other optical fiber. The seismic system uses Manchester II code for data transmission.

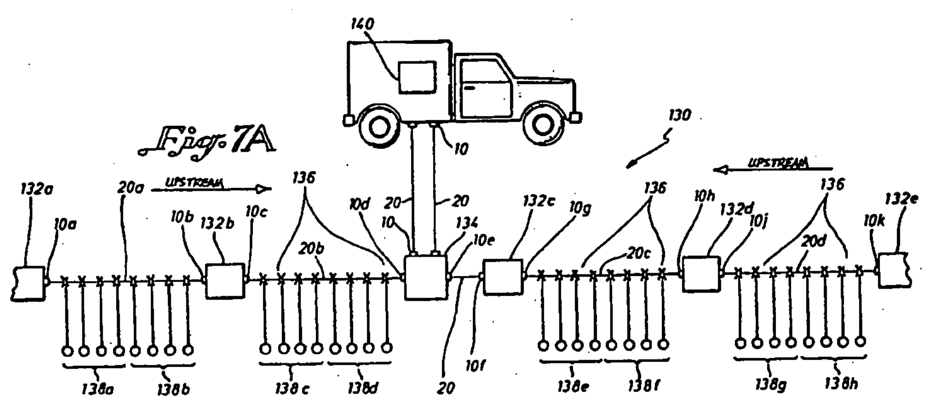


Fig. 7A

GB 2 087 680 A

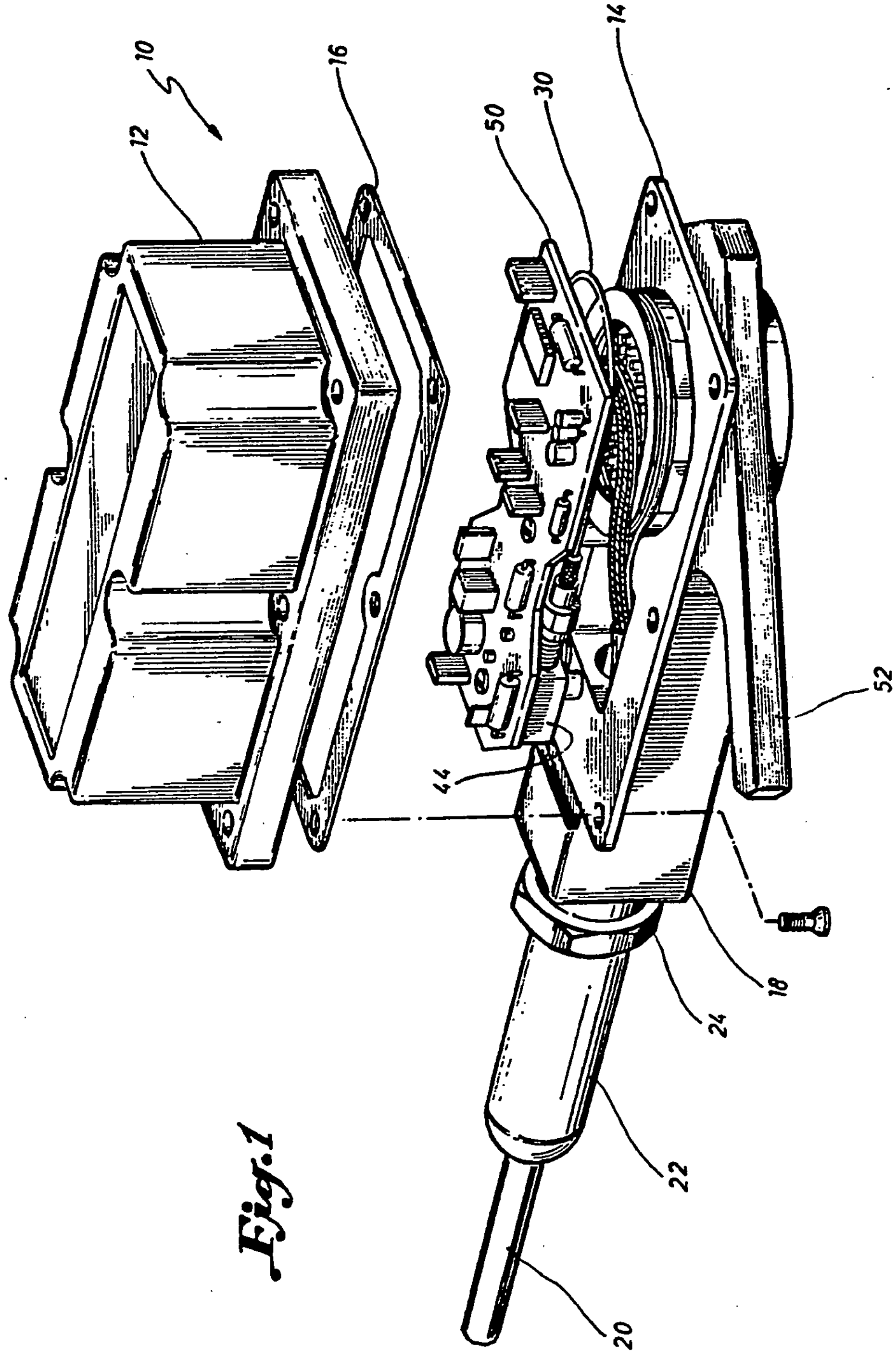


Fig.1

2087680

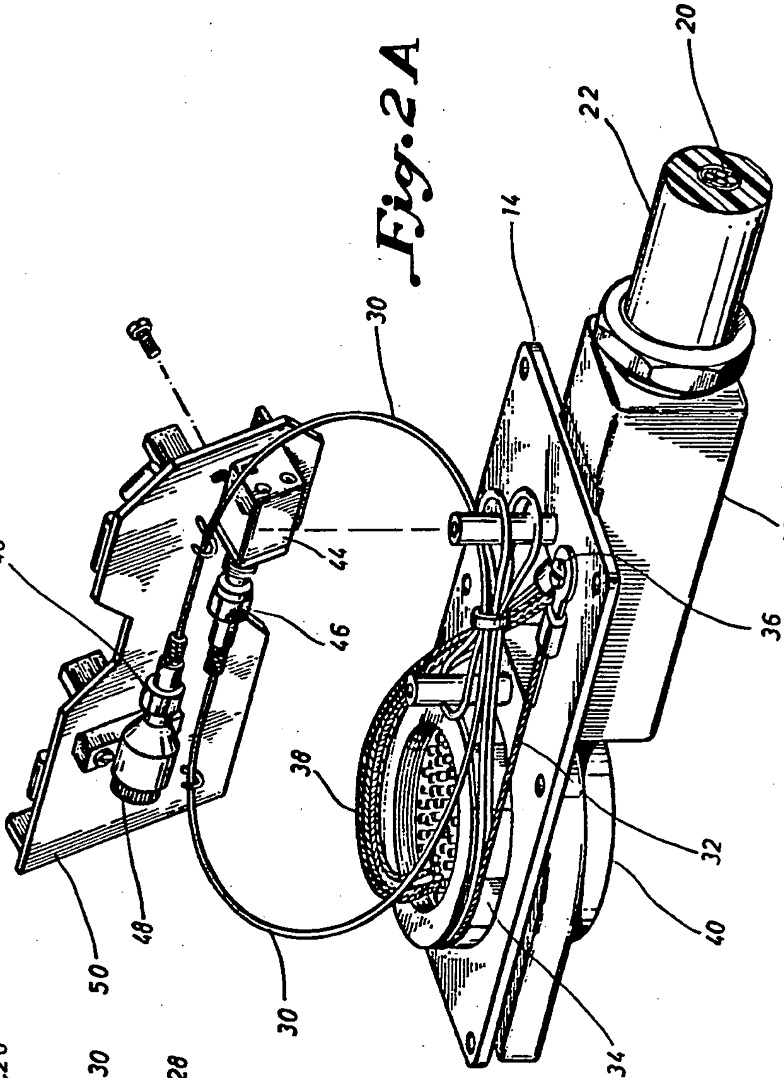


Fig. 2A

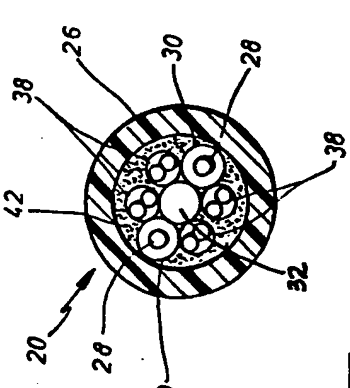
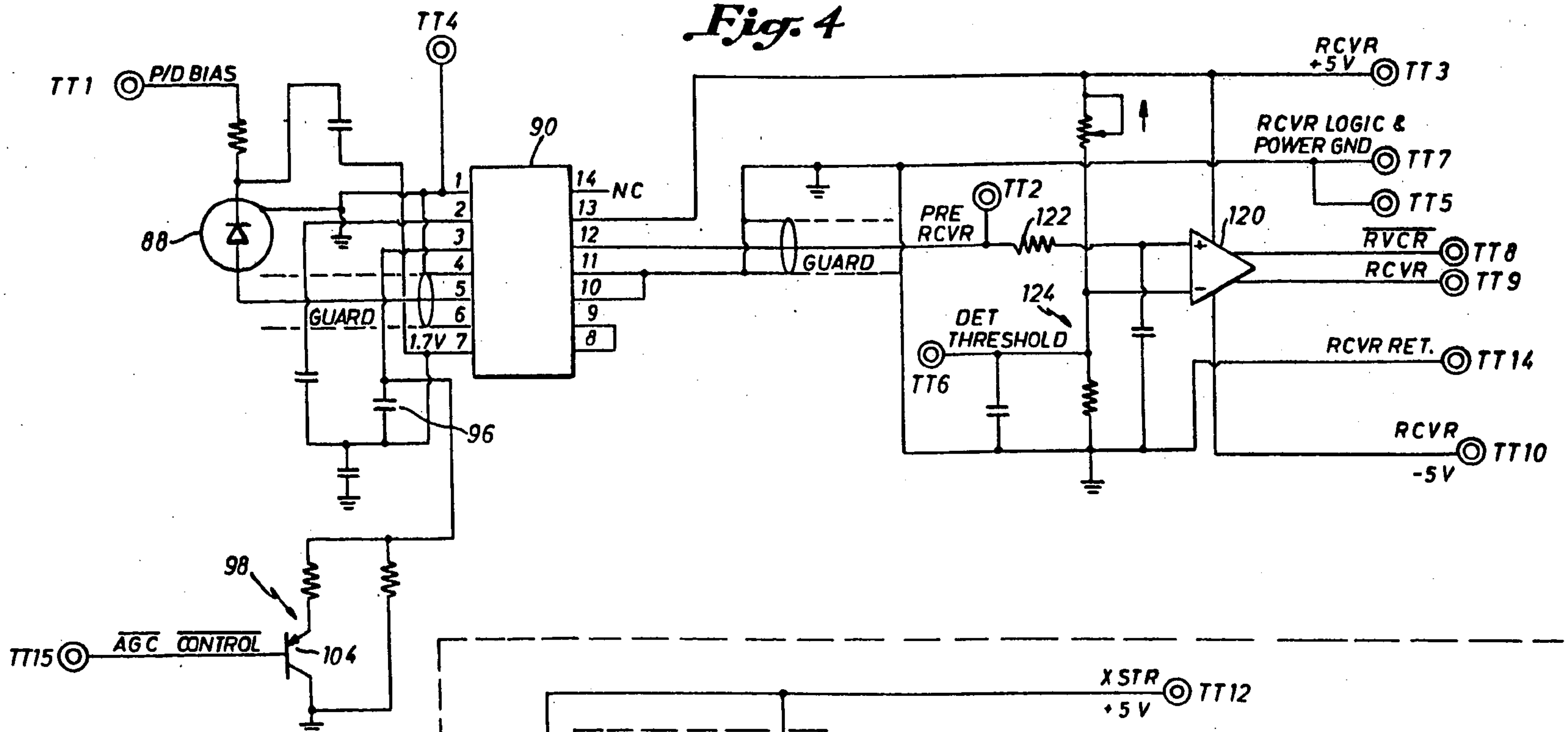
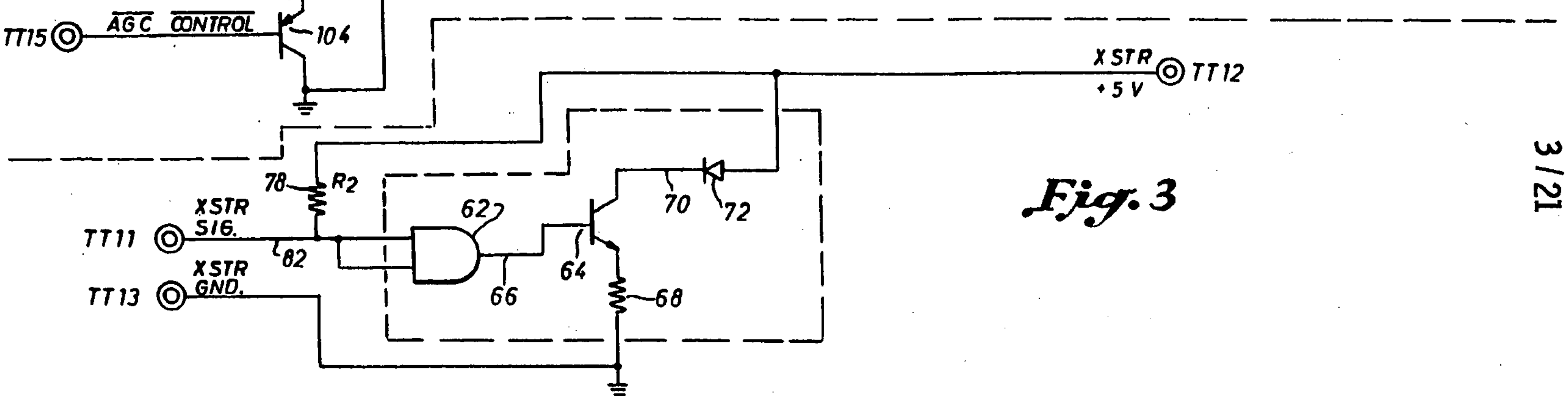


Fig. 2B


TT4
TT1
P/D BIAS
90
88
14 NC
13
12
11
10
9
8
1
2
3
4
5
6
1.7V 7
GUARD
96
GUARD
PRE RCVR
TT2
122
124
DET THRESHOLD
TT6
120
RCVR +5V
TT3
RCVR LOGIC & POWER GND
TT7
TT5
RVCR
TT8
RCVR
TT9
RCVR RET.
TT14
RCVR -5V
TT10
98
TT15
AGC CONTROL
104
Fig. 4


XSTR +5V
TT12
78
R2
XSTR SIG.
TT11
82
XSTR GND.
TT13
62
66
64
68
70
72
Fig. 3

2087683

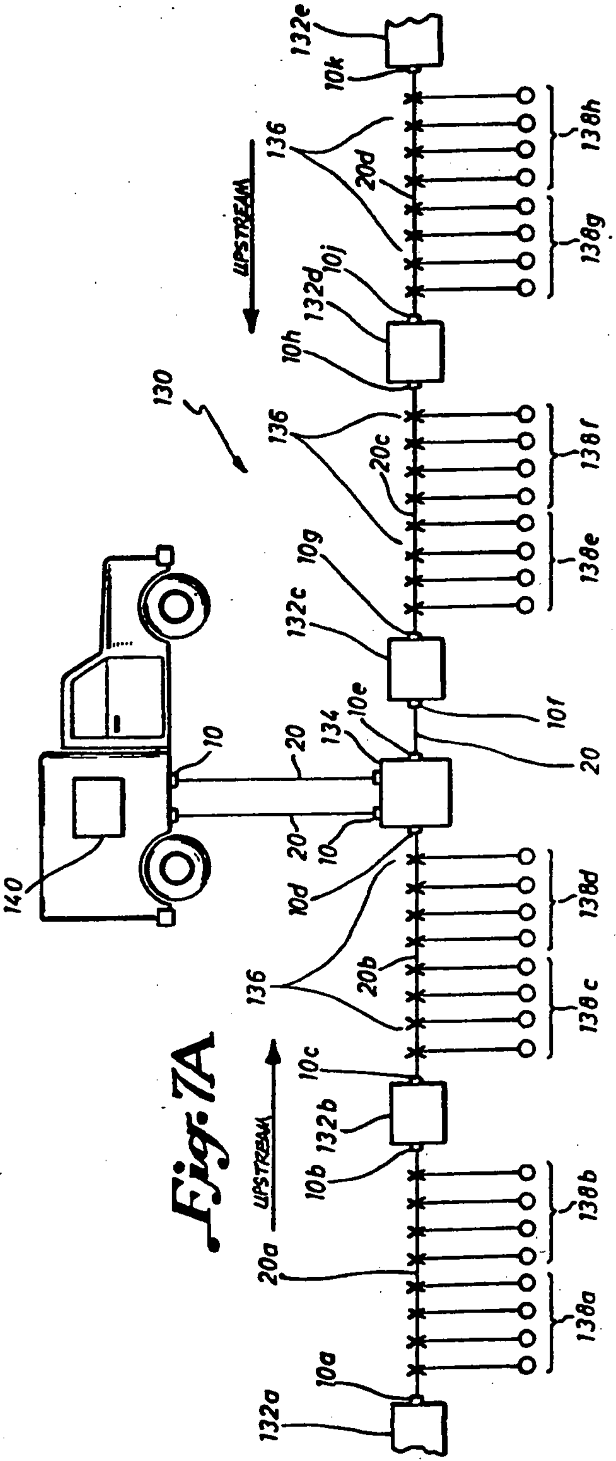


Fig. 7A

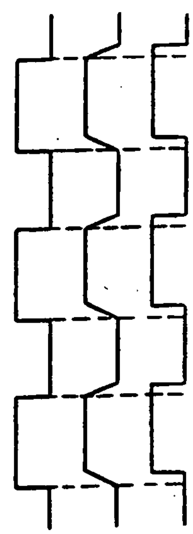


Fig. 5A
Fig. 5B
Fig. 5C

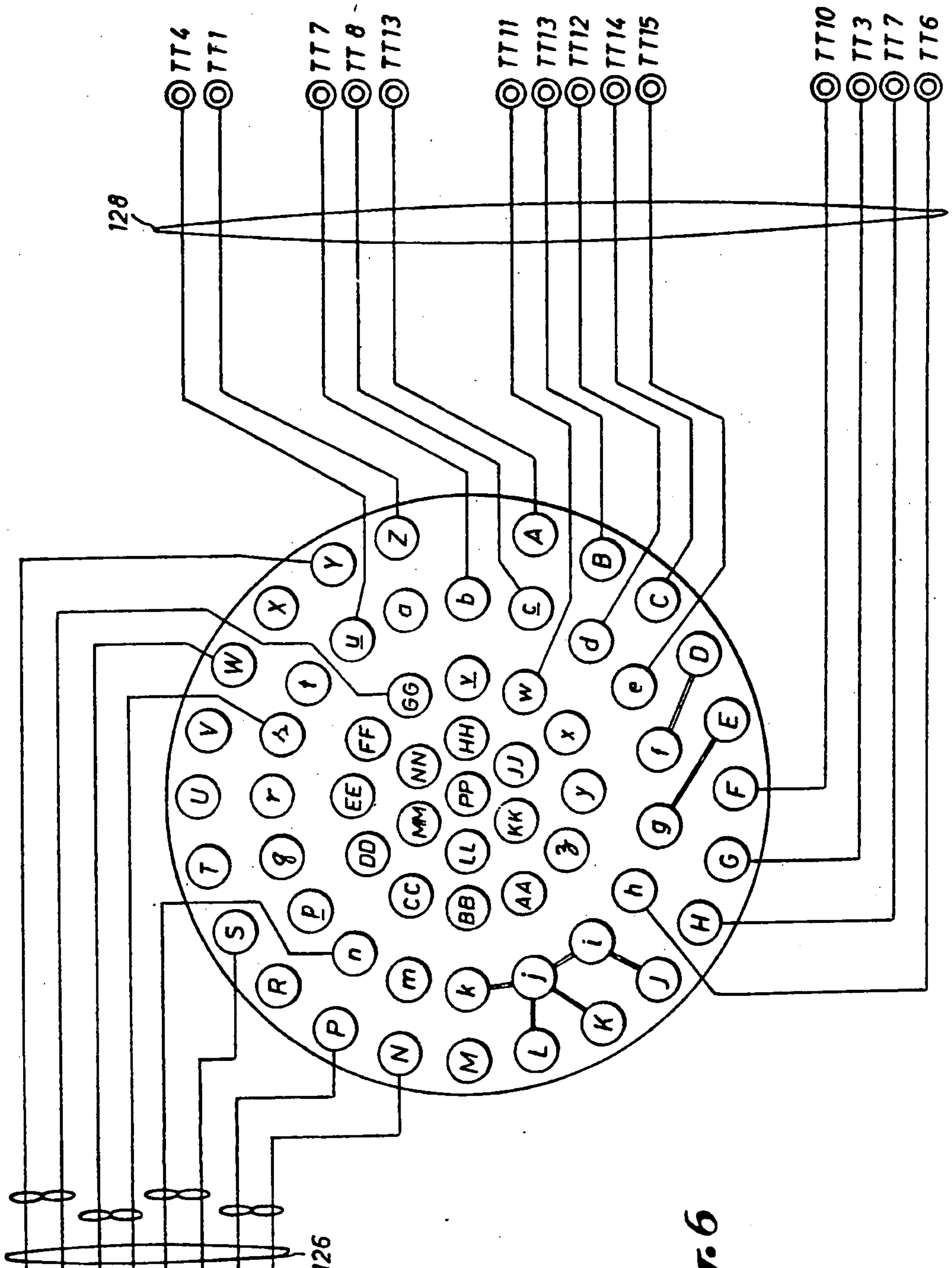
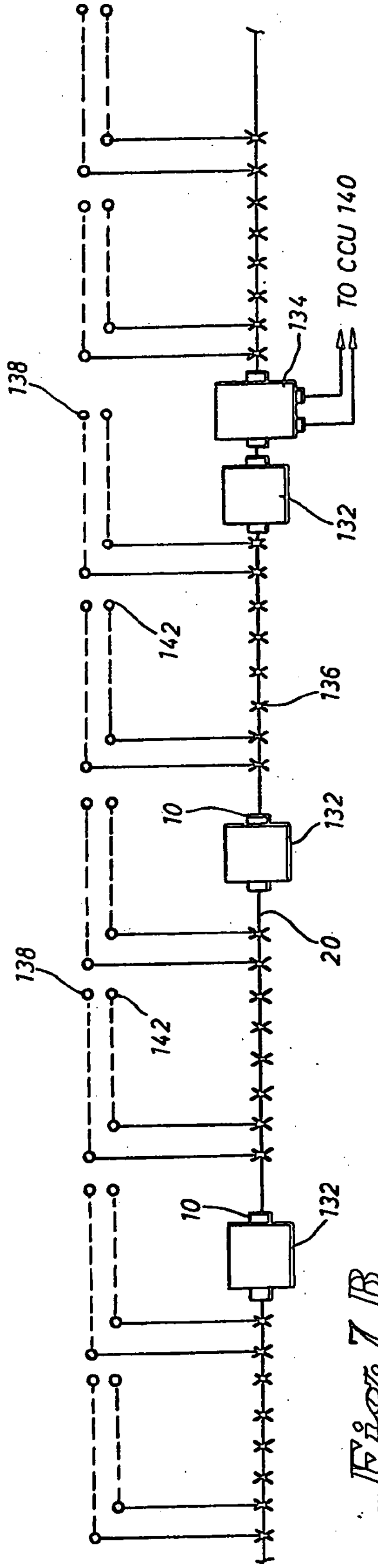
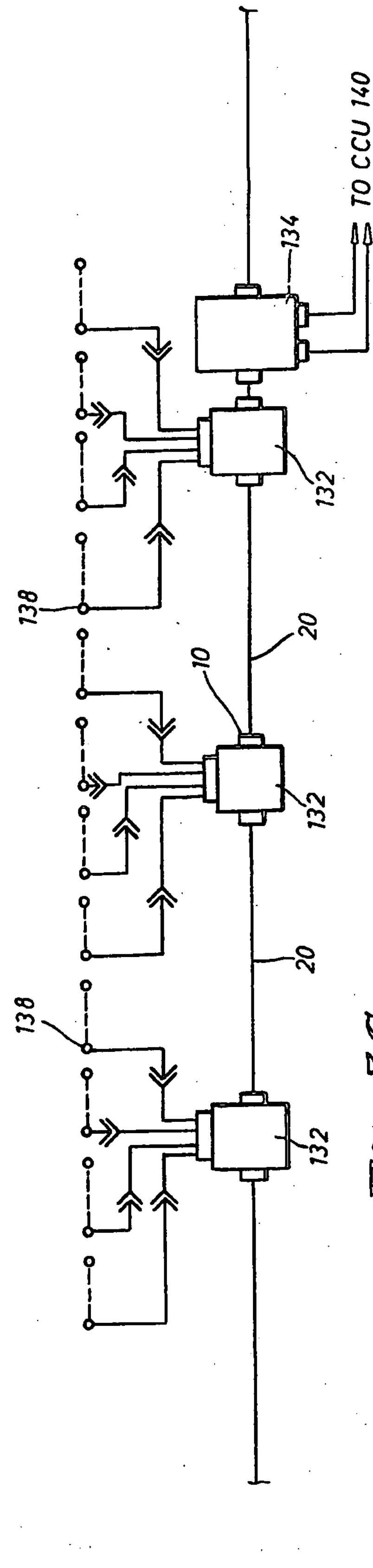

TT4
TT1
TT7
TT8
TT13
TT11
TT13
TT12
TT14
TT15
TT10
TT3
TT7
TT6
128
126

Fig. 6



138
138
142
142
136
134
TO CCU 140
132
10
132
20
10
132

Fig. 7B



TO CCU 140
134
132
138
10
20
132
20
138
132

Fig. 7C

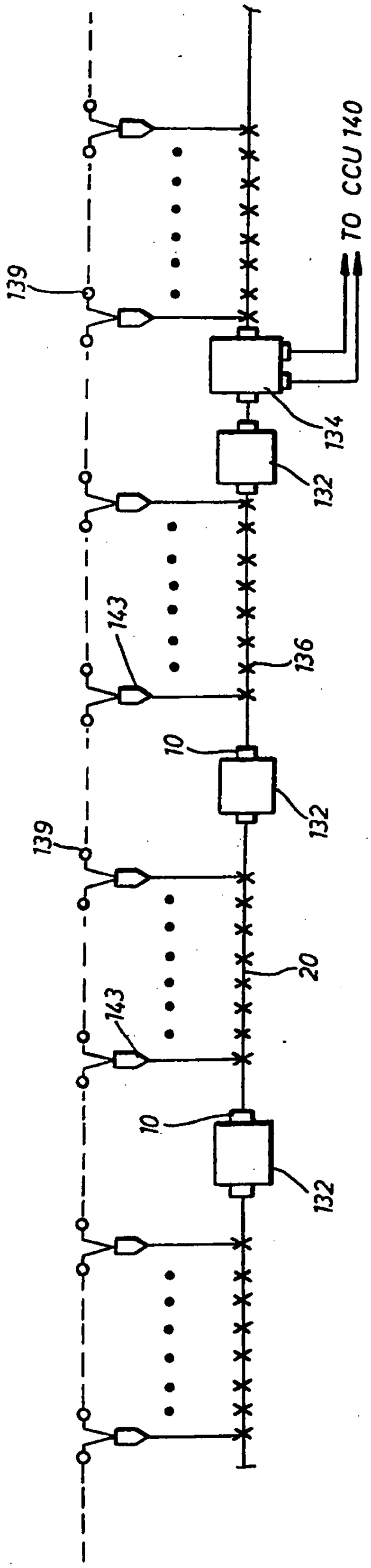

139
143
10
132
20
136
134
TO CCU 140

Fig. 7D

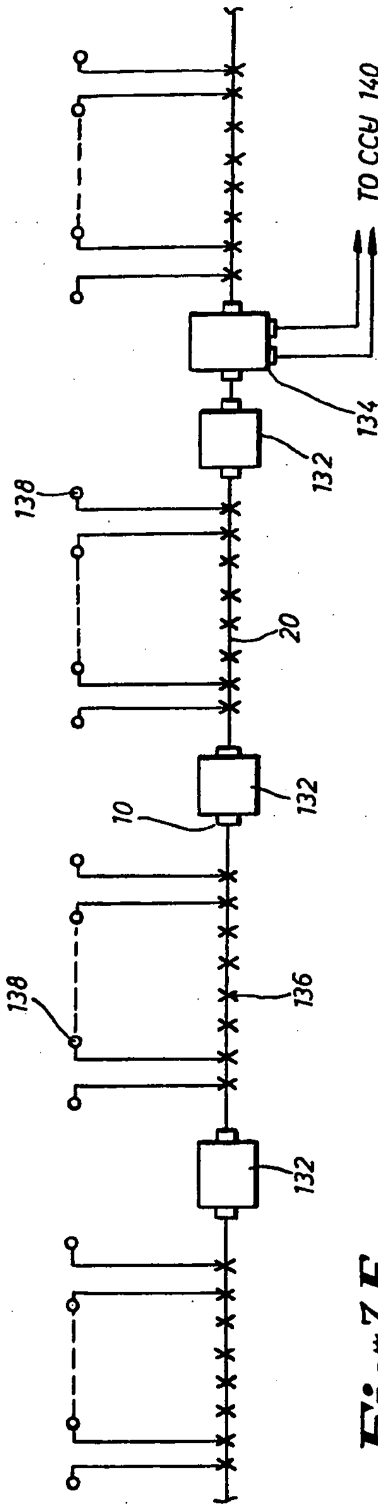

138
10
132
20
136
134
TO CCU 140

Fig. 7E

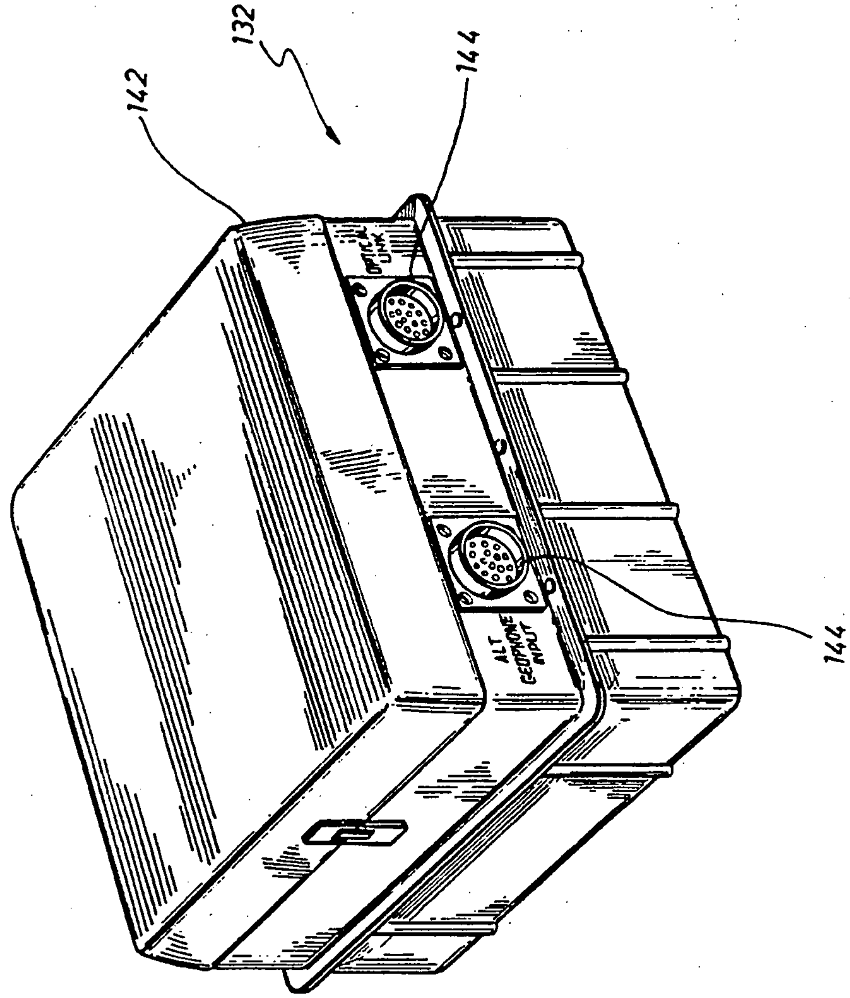


Fig. 8

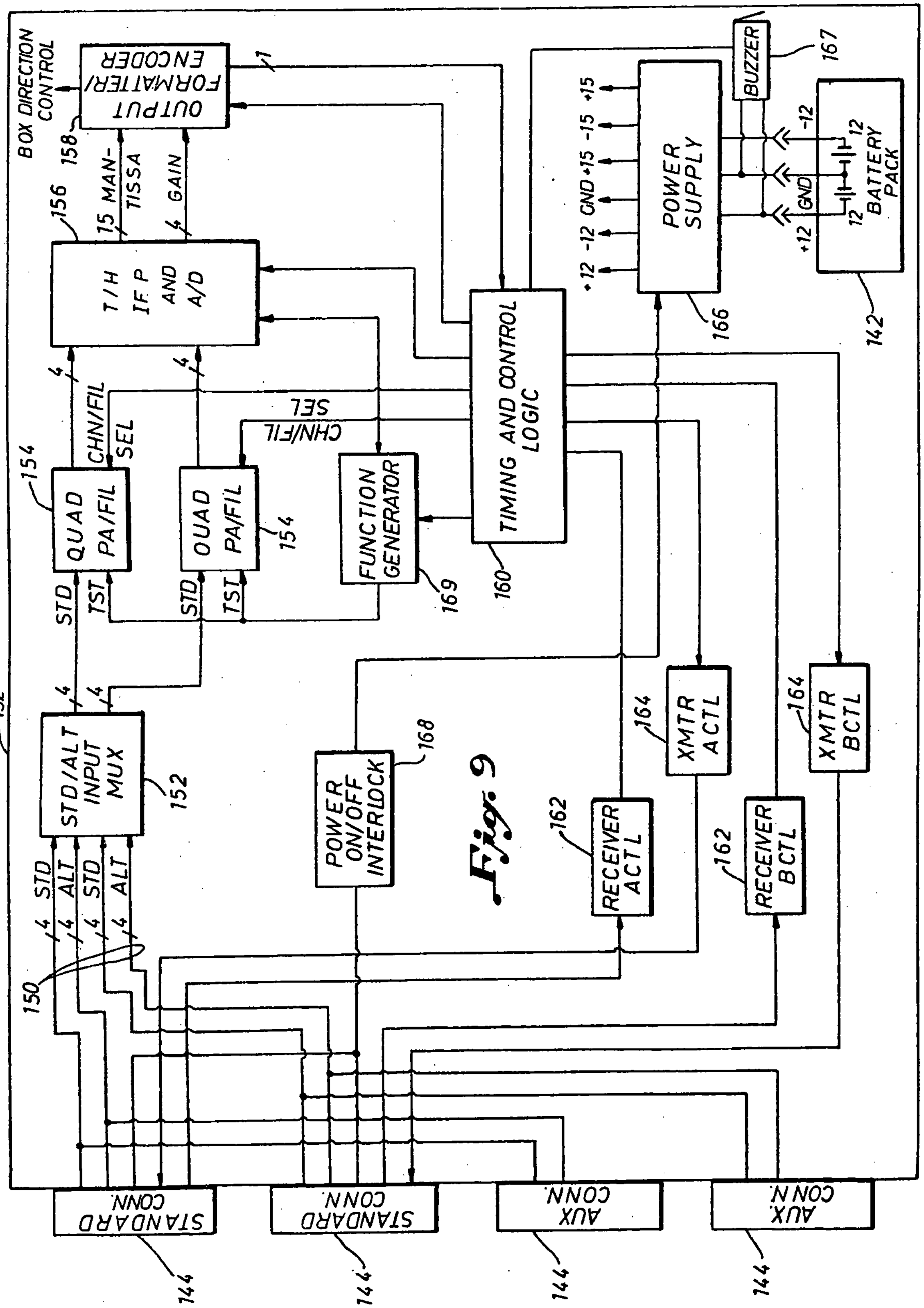
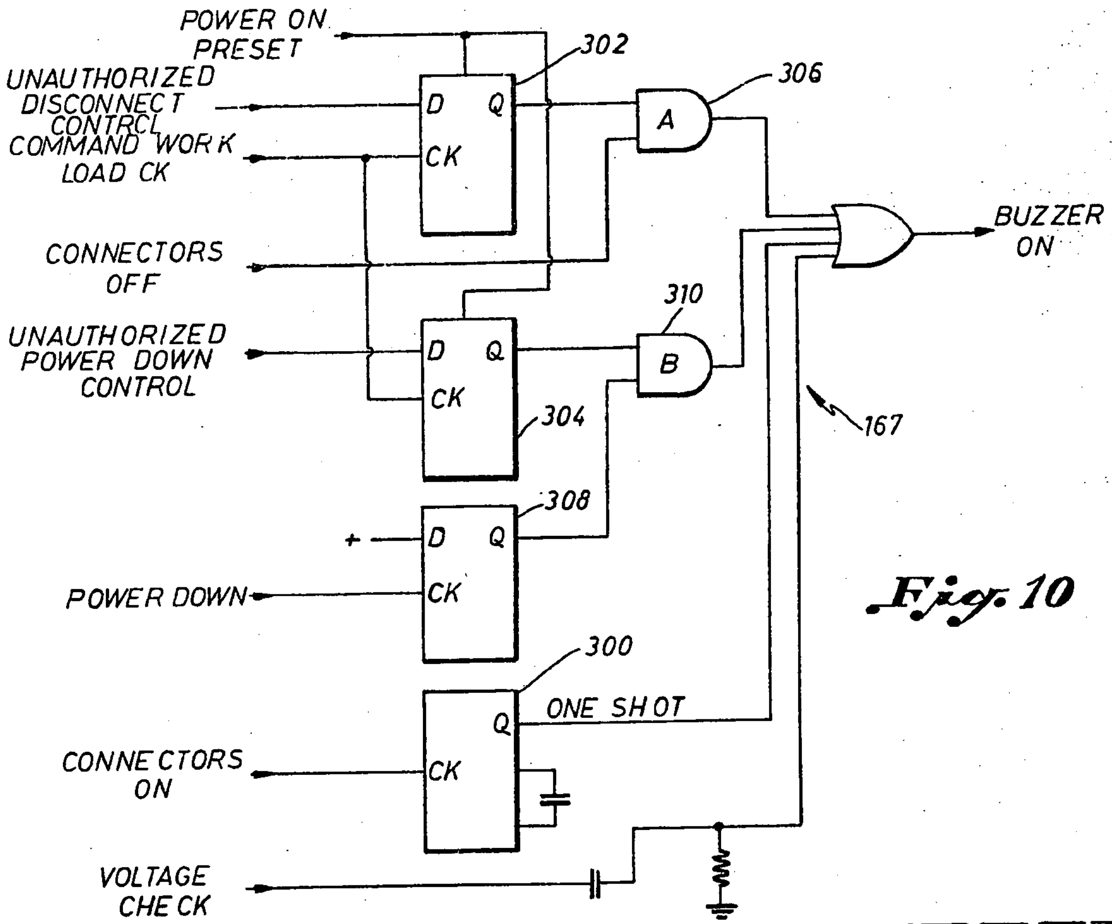
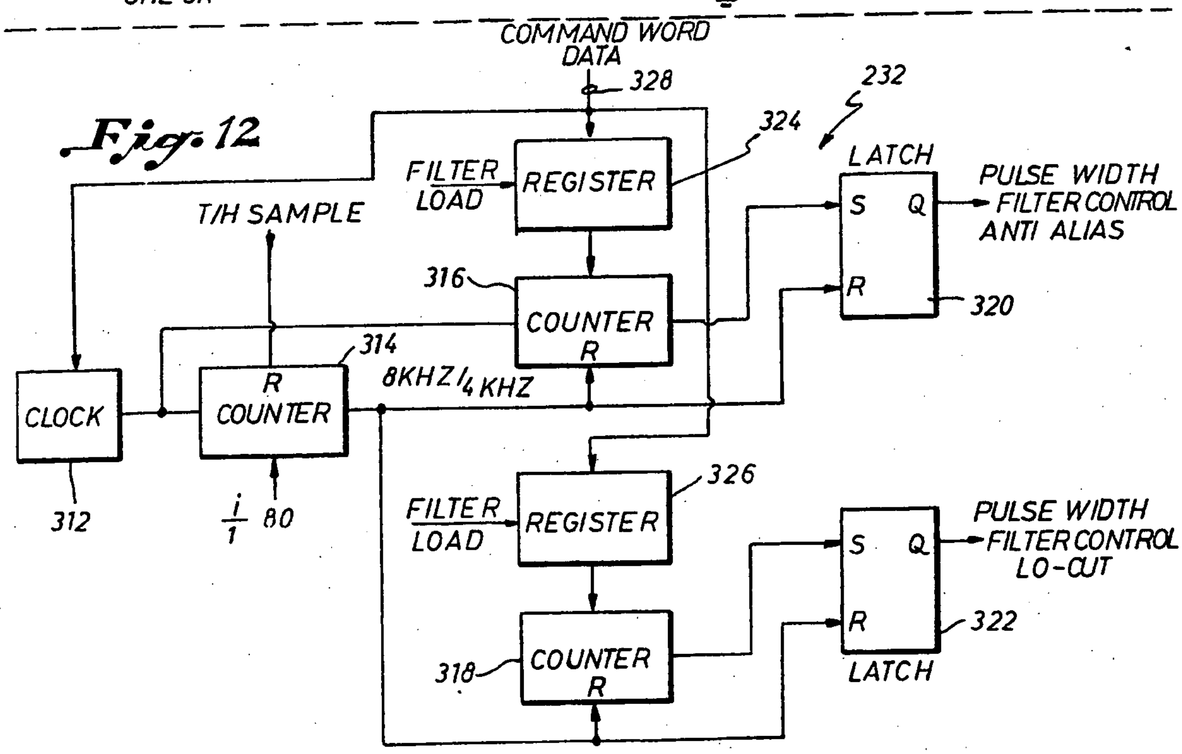

BOX DIRECTION CONTROL
OUTPUT FORMATTER/ENCODER
158
156
15 MANTISSA
4 GAIN
T/H IFP AND A/D
TIMING AND CONTROL LOGIC
160
POWER SUPPLY
166
BUZZER
167
BATTERY PACK
142
+12 -12 GND +15 -15 +15
CHN/FIL SEL
QUAD PA/FIL
154
FUNCTION GENERATOR
169
STD
TST
STD/ALT INPUT MUX
152
132
150
POWER ON/OFF INTERLOCK
168
RECEIVER ACTL
162
XMTR ACTL
164
RECEIVER BCTL
XMTR BCTL
STANDARD CONN.
AUX CONN.
144

Fig. 9



POWER ON PRESET
302
UNAUTHORIZED DISCONNECT CONTROL
COMMAND WORK LOAD CK
D Q
CK
306
A
CONNECTORS OFF
BUZZER ON
310
UNAUTHORIZED POWER DOWN CONTROL
B
304
167
308
+
POWER DOWN
300
ONE SHOT
CONNECTORS ON
VOLTAGE CHECK

Fig. 10



COMMAND WORD DATA
328
232
324
LATCH
FILTER LOAD
REGISTER
PULSE WIDTH FILTER CONTROL ANTI ALIAS
T/H SAMPLE
316
COUNTER R
320
314
8KHZ/4KHZ
CLOCK
R COUNTER
312
i/1 80
326
REGISTER
PULSE WIDTH FILTER CONTROL LO-CUT
322
318
COUNTER R
LATCH

Fig. 12

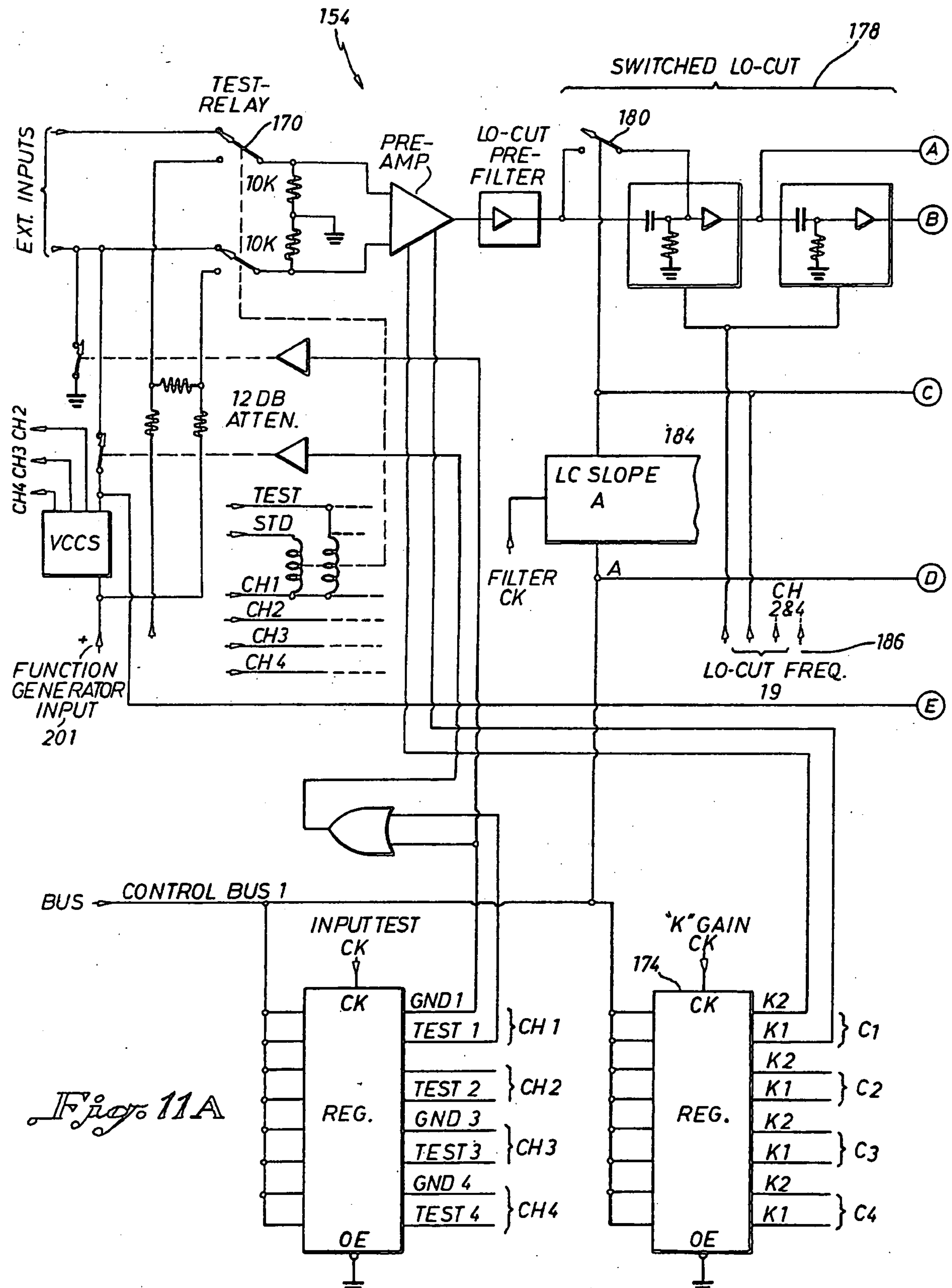

154
178
SWITCHED LO-CUT
TEST-RELAY
170
180
LO-CUT PRE-FILTER
PRE-AMP
EXT. INPUTS
10K
10K
A
B
C
D
E
12 DB ATTEN.
184
LC SLOPE A
CH4 CH3 CH2
VCCS
TEST
STD
CH1
CH2
CH3
CH4
FILTER CK
A
CH 2&4
186
LO-CUT FREQ. 19
FUNCTION GENERATOR INPUT
201
BUS
CONTROL BUS 1
INPUT TEST CK
"K" GAIN CK
174
CK
GND 1
TEST 1
CH 1
TEST 2
CH 2
GND 3
TEST 3
CH 3
GND 4
TEST 4
CH 4
REG.
OE
K2
K1
C1
C2
C3
C4

Fig. 11A

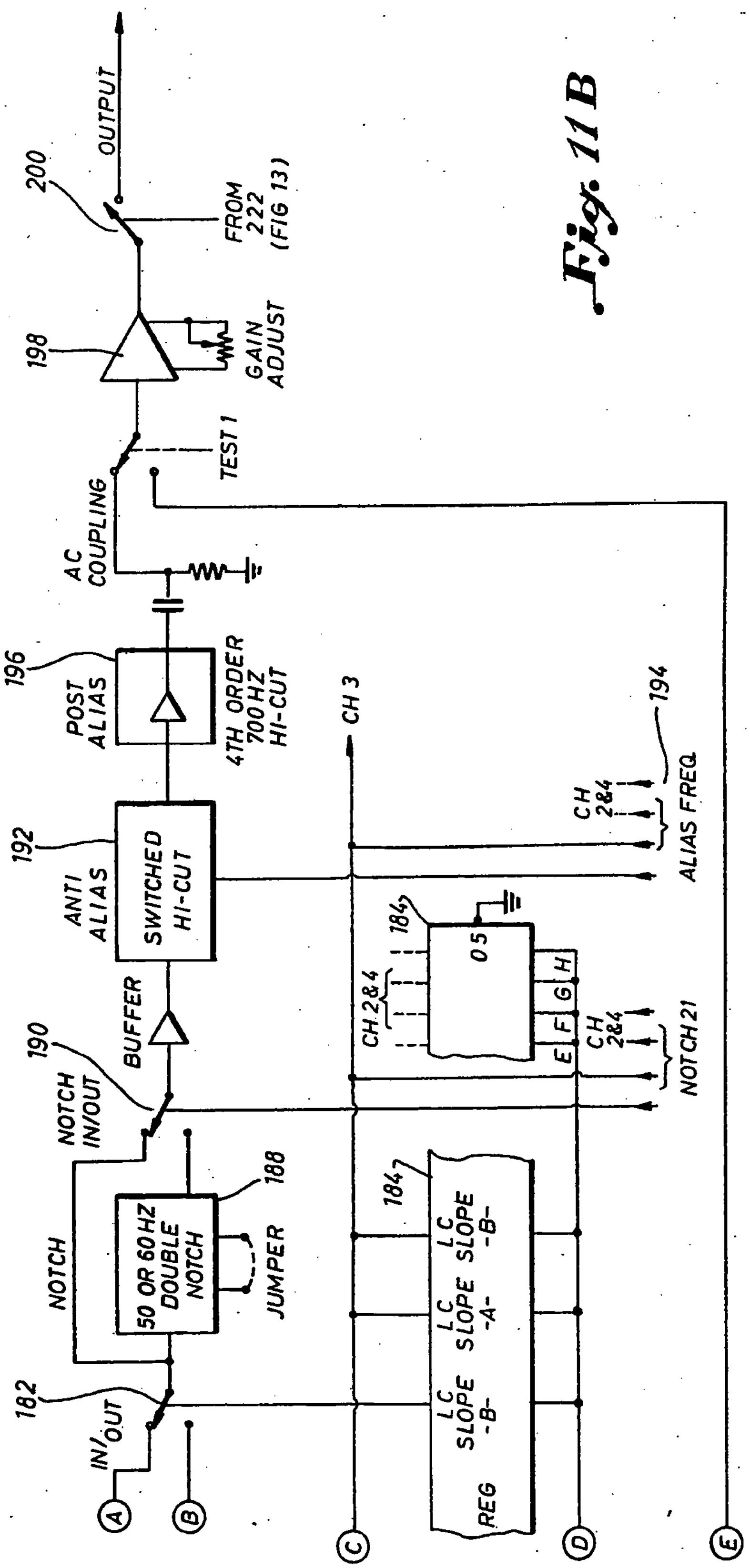
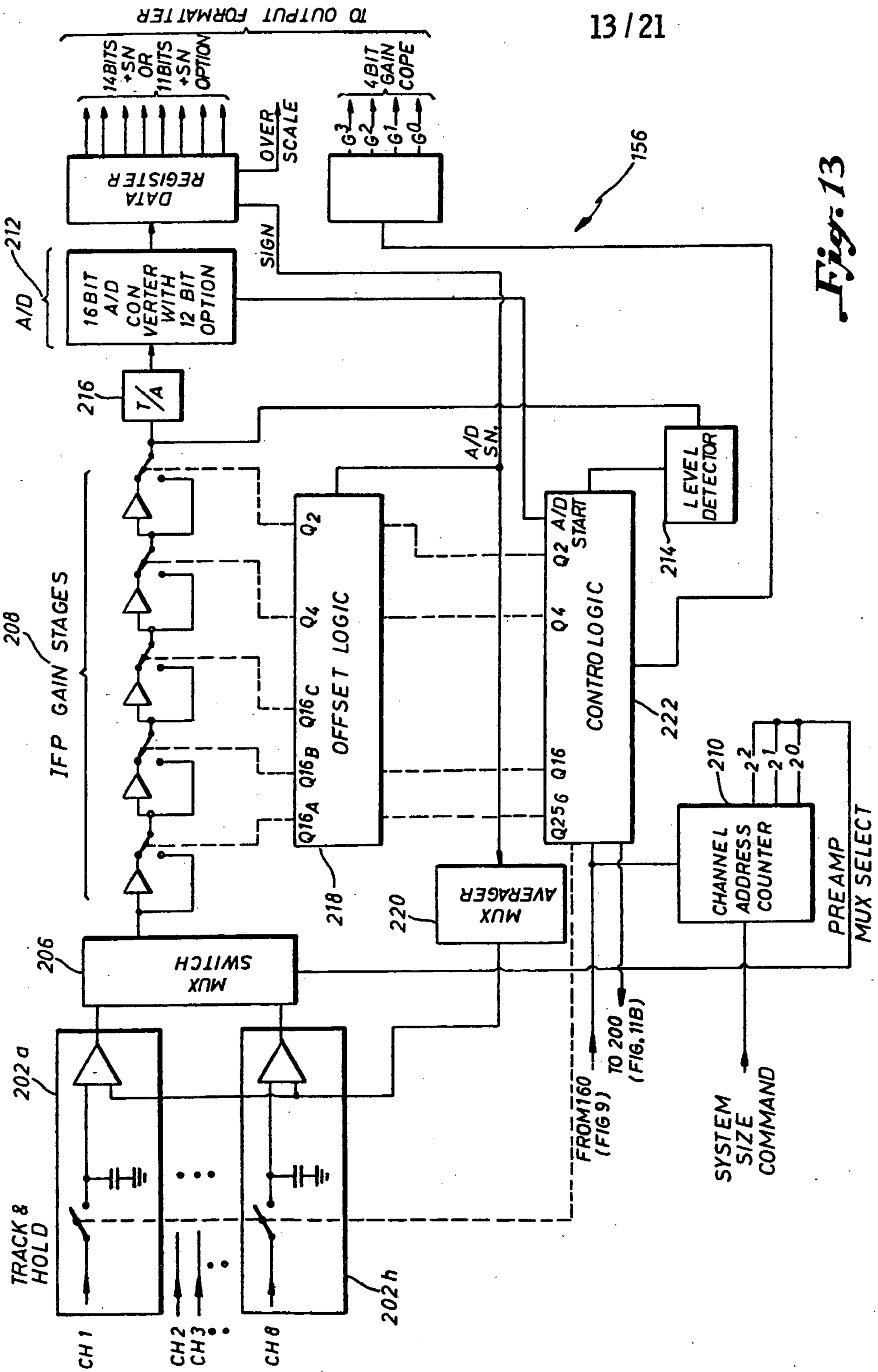

OUTPUT
200
FROM
222
(FIG 13)
198
GAIN
ADJUST
TEST 1
AC
COUPLING
196
POST
ALIAS
4TH ORDER
700 HZ
HI-CUT
CH 3
194
192
ANTI
ALIAS
SWITCHED
HI-CUT
CH
2&4
ALIAS FREQ
184
05
CH 2&4
E
F
G
H
CH
2&4
NOTCH 21
BUFFER
190
NOTCH
IN/OUT
188
50 OR 60 HZ
DOUBLE
NOTCH
JUMPER
NOTCH
184
LC
SLOPE
-B-
LC
SLOPE
-A-
LC
SLOPE
-B-
REG
182
IN/OUT
A
B
C
D
E

Fig. 11 B



TO OUTPUT FORMATTER
14BITS +SN OR 11BITS +SN OPTION
4BIT GAIN COPE
G3
G2
G1
G0
OVER SCALE
DATA REGISTER
SIGN
212
A/D
16BIT A/D CON VERTER WITH 12 BIT OPTION
216
T/A
156
A/D S.N.
LEVEL DETECTOR
214
208
IFP GAIN STAGES
Q2
Q4
Q16 C
Q16B
Q16A
OFFSET LOGIC
218
Q2 A/D START
Q4
Q16
Q256
CONTRO LOGIC
222
210
2^2
2^1
2^0
CHANNEL ADDRESS COUNTER
PREAMP MUX SELECT
MUX AVERAGER
220
206
MUX SWITCH
202a
202h
TRACK & HOLD
CH1
CH2
CH3
CH8
FROM160 (FIG 9)
TO 200 (FIG, 11B)
SYSTEM SIZE COMMAND

Fig. 13

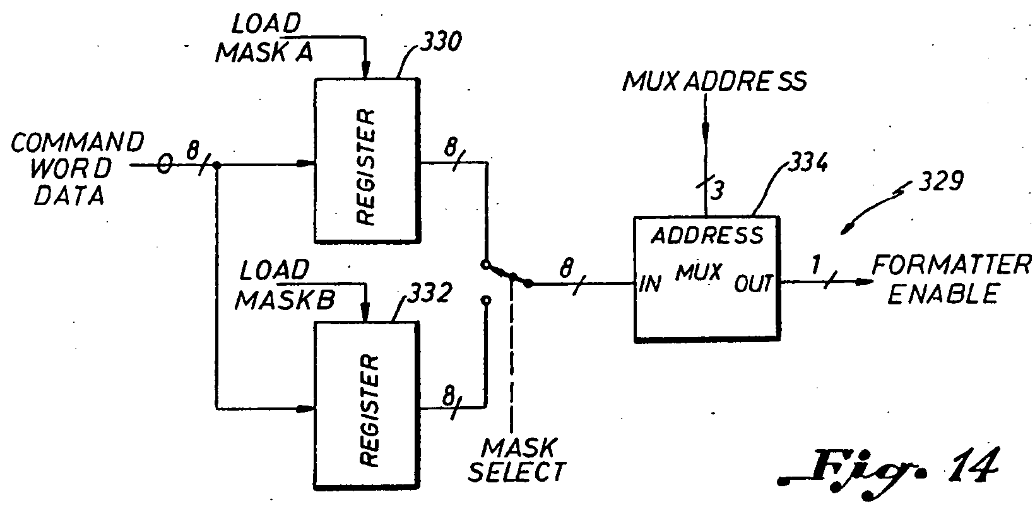


Fig. 14

Fig 16

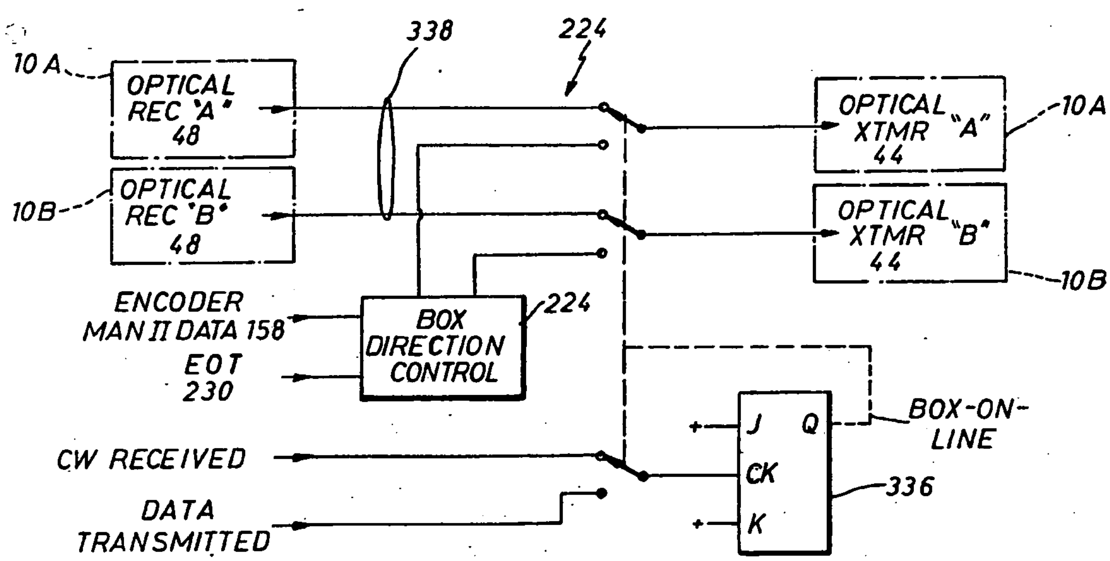
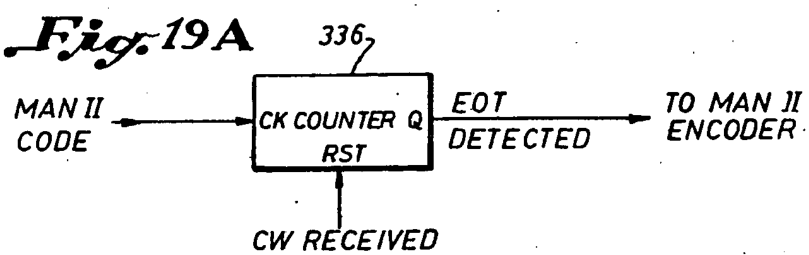


Fig. 19A



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15 / 21

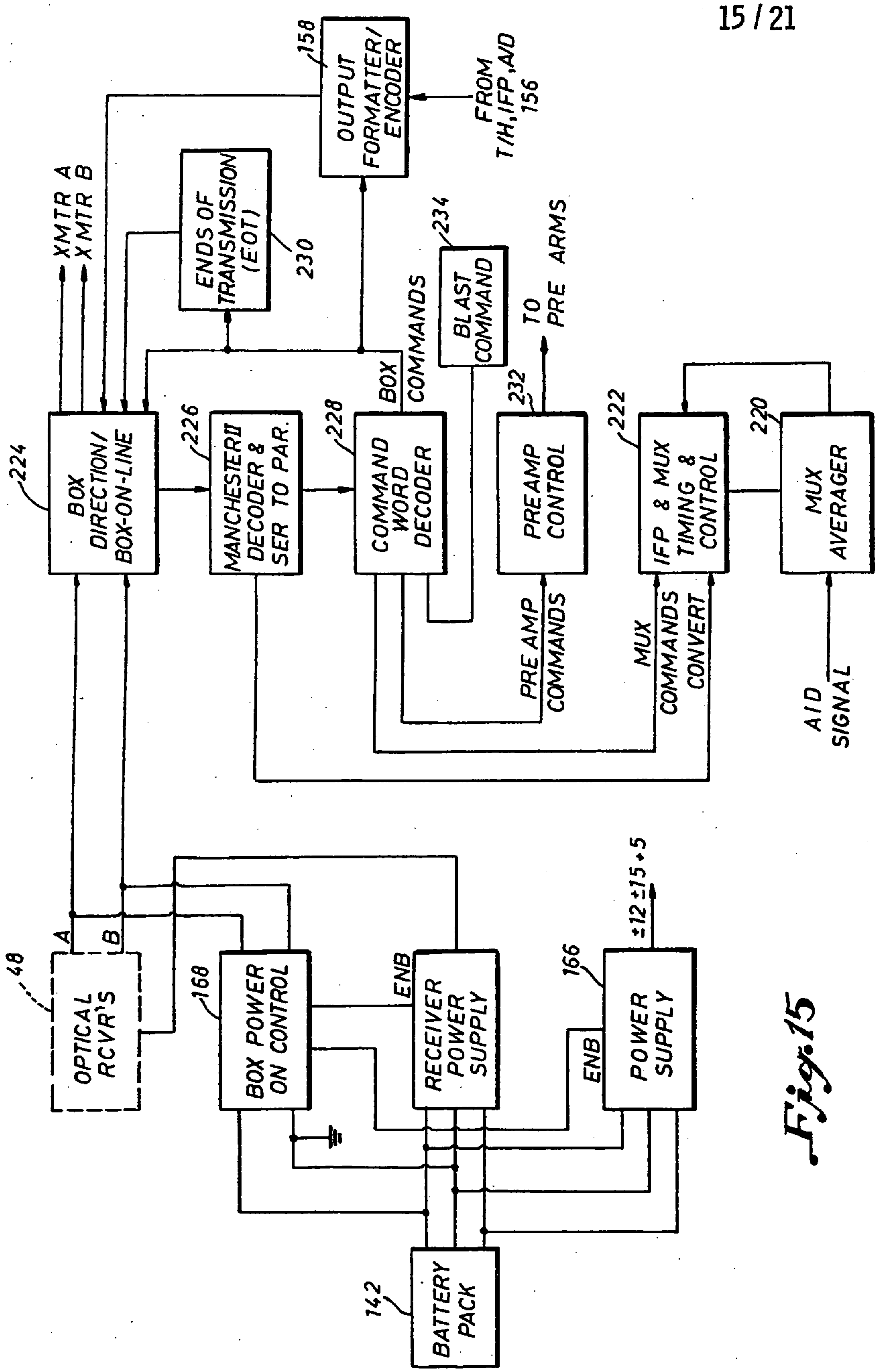


Fig.15

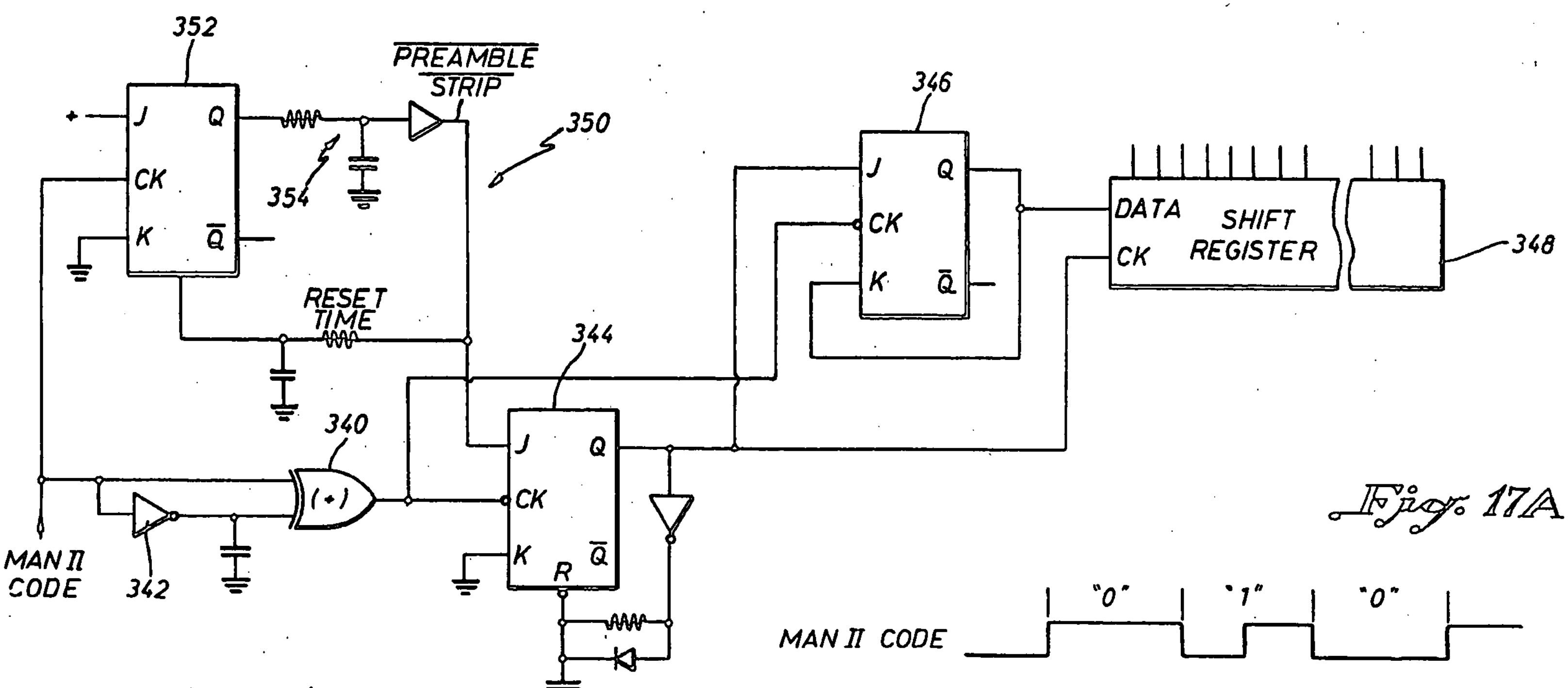


Fig. 17B

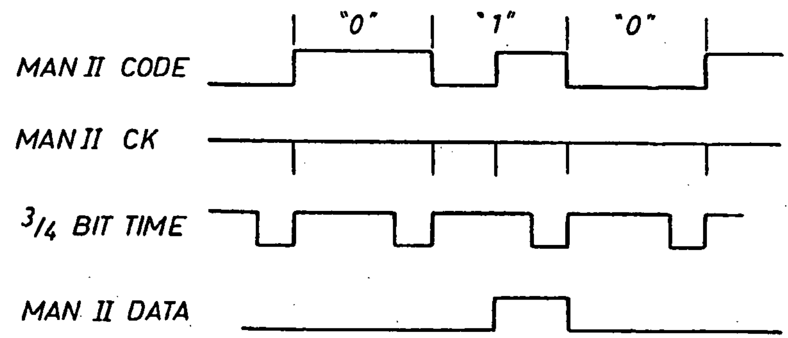


Fig. 17A

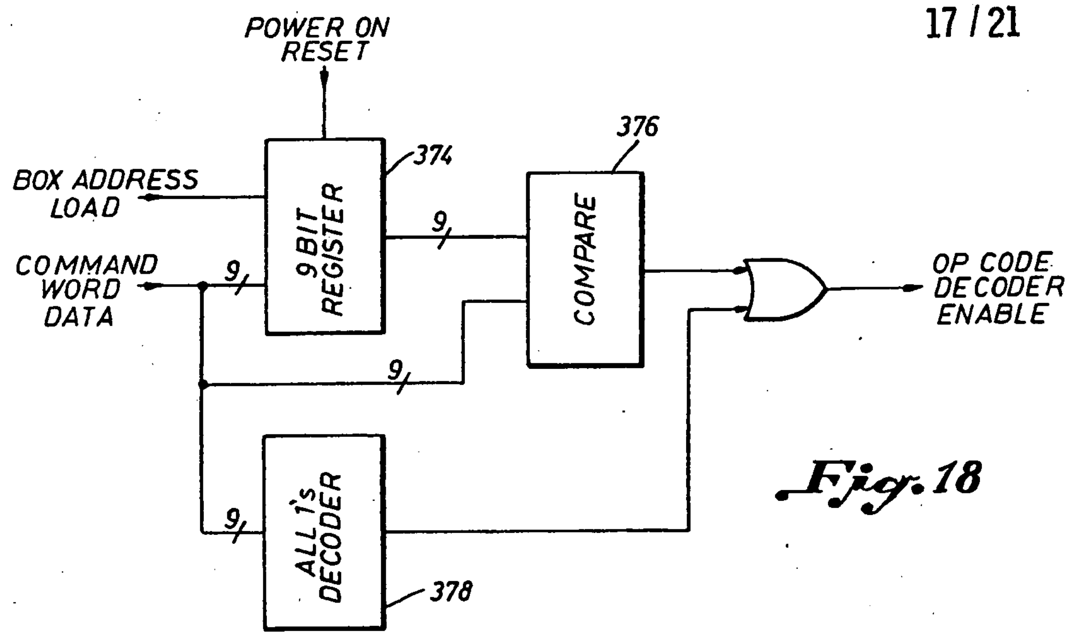


Fig. 18

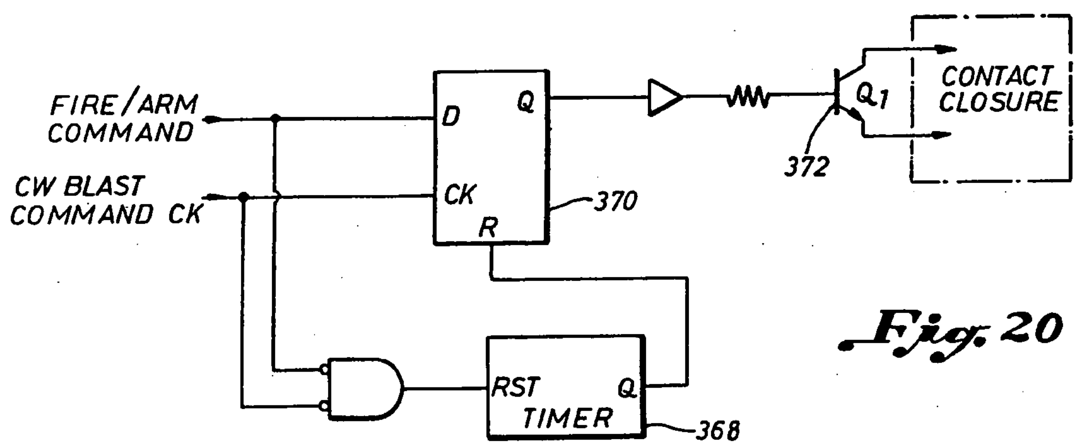


Fig. 20

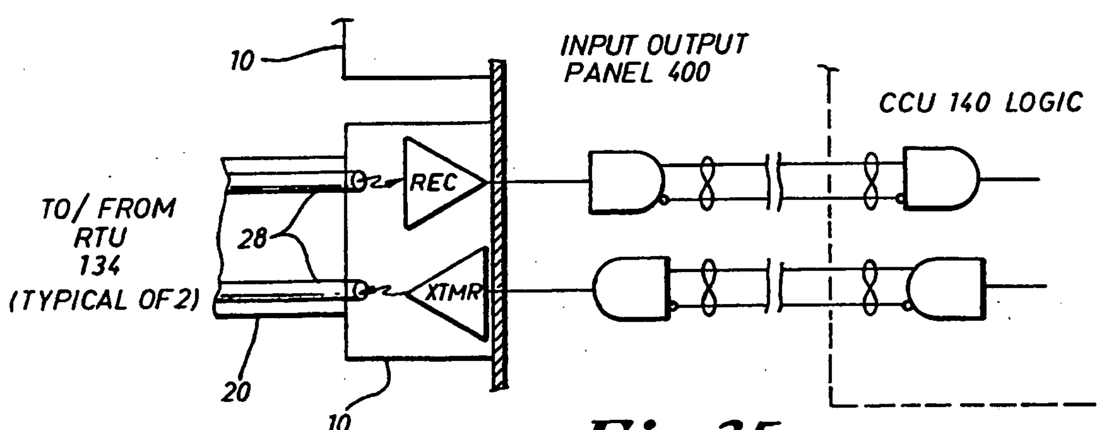


Fig. 25

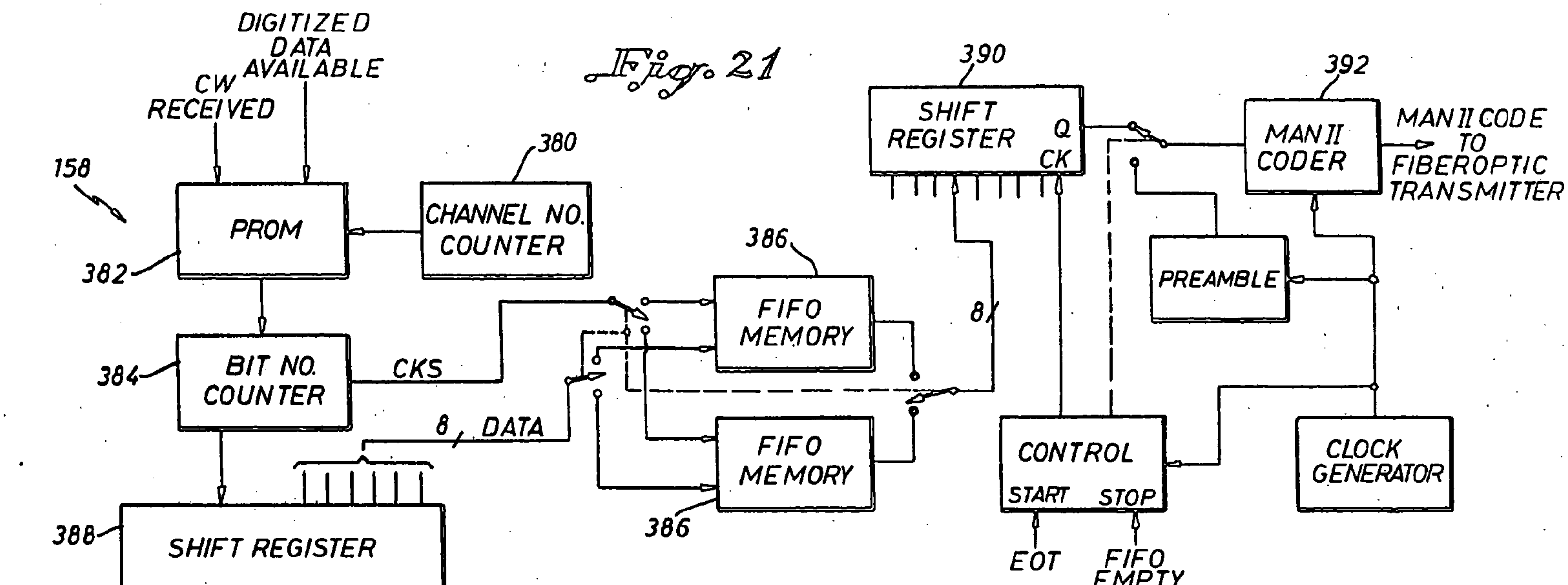


Fig. 21

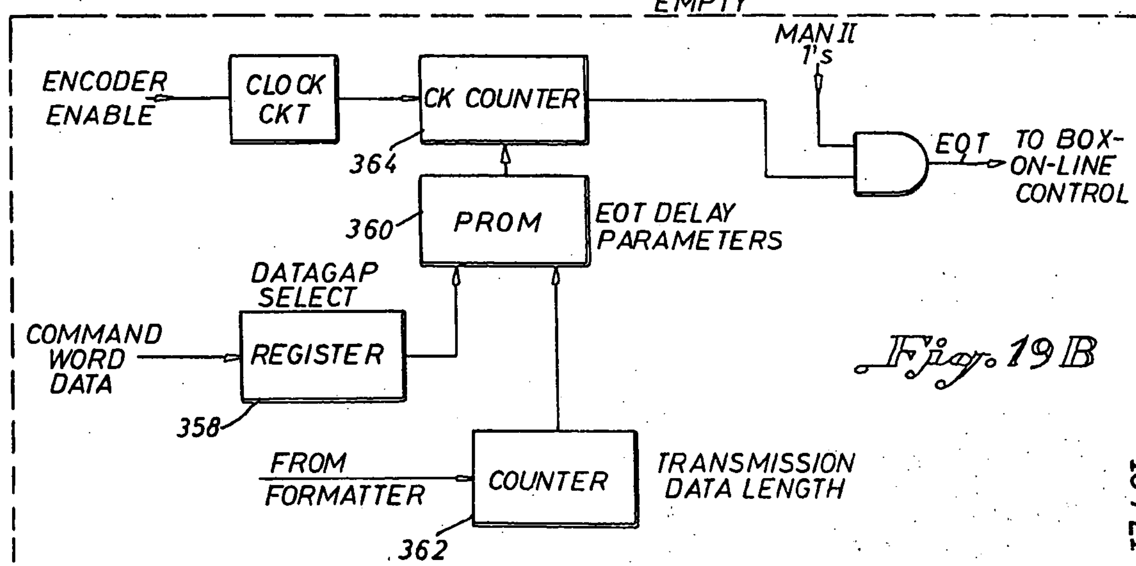


Fig. 19B

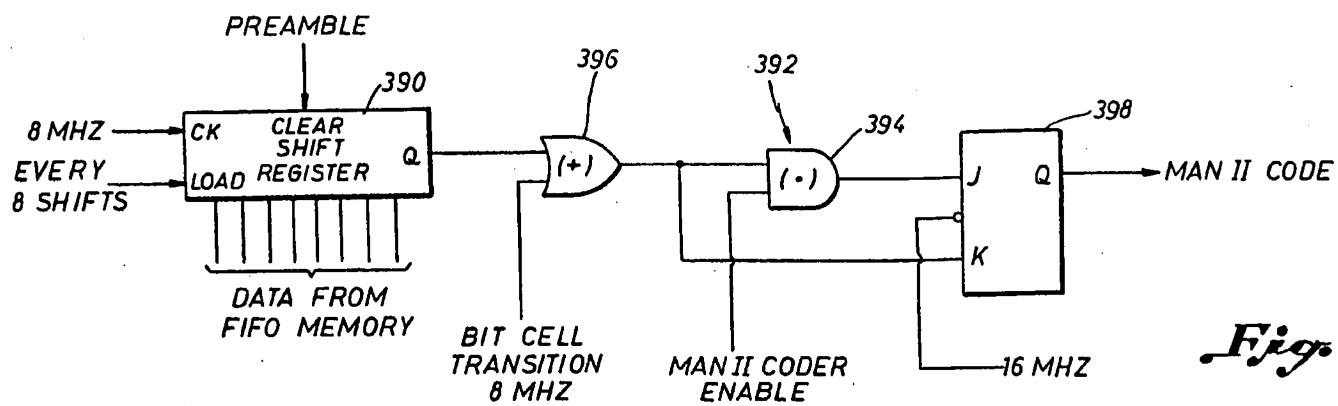

PREAMBLE
390
8 MHZ
EVERY 8 SHIFTS
CK
LOAD
CLEAR SHIFT REGISTER
Q
DATA FROM FIFO MEMORY
396
(+)
BIT CELL TRANSITION 8 MHZ
392
394
(•)
MAN II CODER ENABLE
398
J
K
Q
16 MHZ
MAN II CODE

Fig. 22

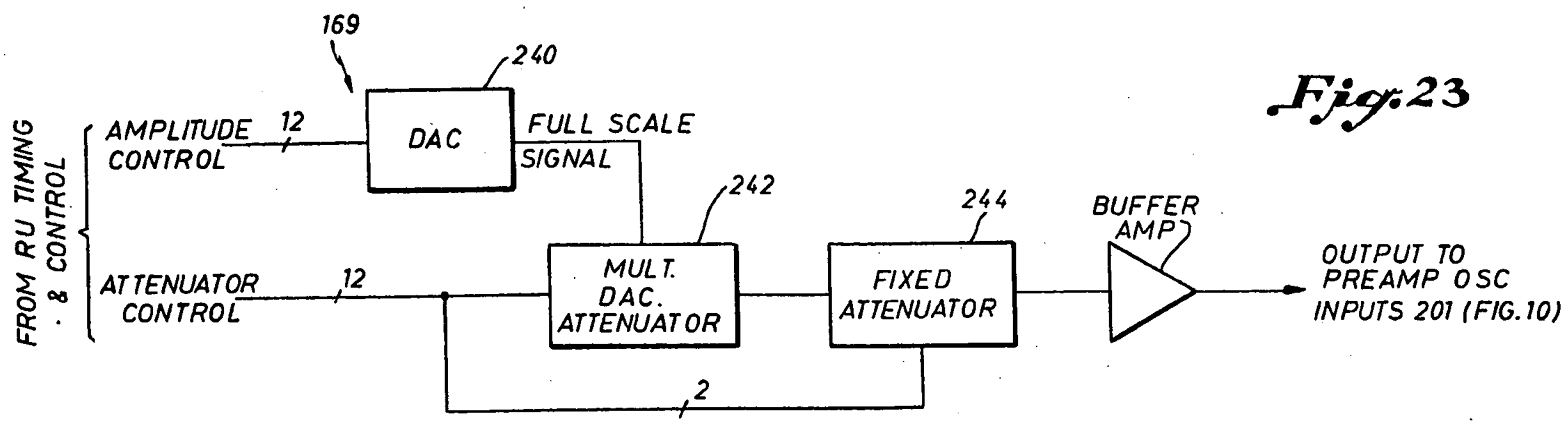
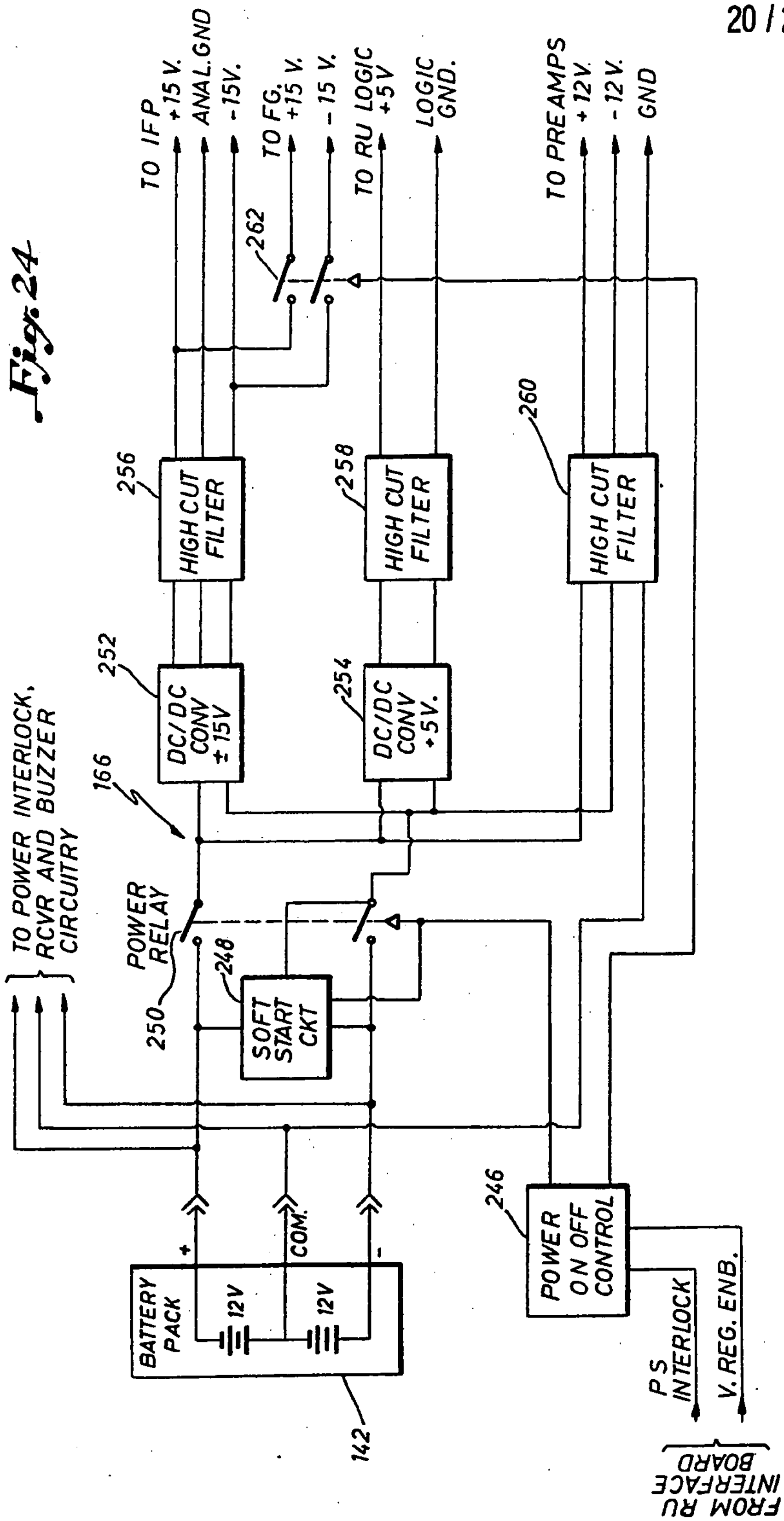

FROM RU TIMING & CONTROL
AMPLITUDE CONTROL
12
169
240
DAC
FULL SCALE SIGNAL
ATTENUATOR CONTROL
12
242
MULT. DAC. ATTENUATOR
244
FIXED ATTENUATOR
2
BUFFER AMP
OUTPUT TO PREAMP OSC INPUTS 201 (FIG.10)

Fig. 23

Fig. 24



TO IFP
+15 V.
ANAL.GND
-15V.
TO FG.
+15 V.
-15 V.
TO RU LOGIC
+5V
LOGIC
GND.
TO PREAMPS
+12V.
-12 V.
GND
262
256
HIGH CUT FILTER
258
HIGH CUT FILTER
260
HIGH CUT FILTER
252
DC/DC CONV ±15V
254
DC/DC CONV +5V.
166
TO POWER INTERLOCK, RCVR AND BUZZER CIRCUITRY
POWER RELAY
248
250
SOFT START CKT
246
POWER ON OFF CONTROL
BATTERY PACK
+
COM.
-
12V
12V
142
PS INTERLOCK
V. REG. ENB.
FROM RU INTERFACE BOARD

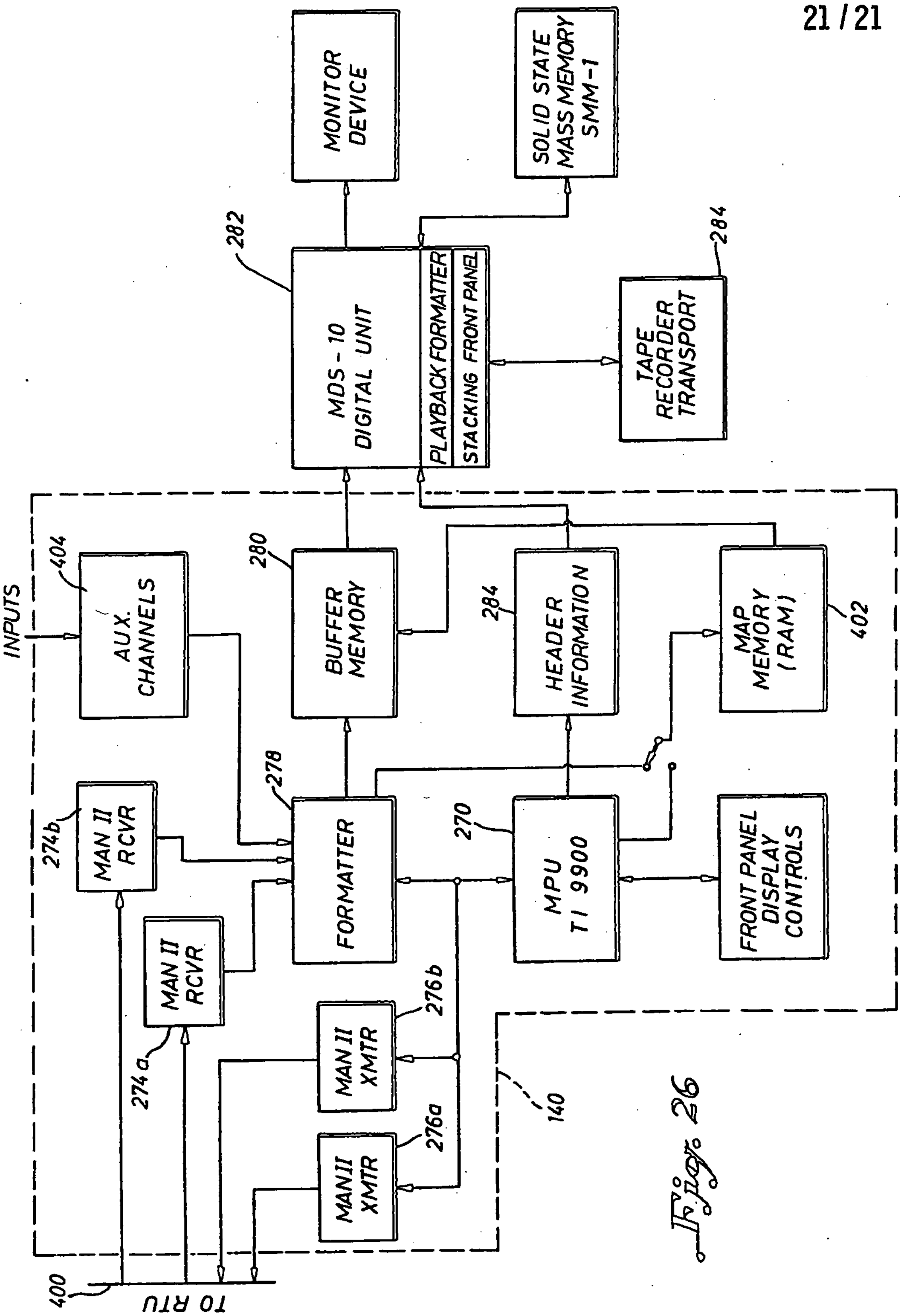

MONITOR DEVICE
SOLID STATE MASS MEMORY SMM-1
282
284
MDS - 10 DIGITAL UNIT
PLAYBACK FORMATTER
STACKING FRONT PANEL
TAPE RECORDER TRANSPORT
INPUTS
404
AUX. CHANNELS
280
BUFFER MEMORY
284
HEADER INFORMATION
MAP MEMORY (RAM)
402
274b
MAN II RCVR
278
FORMATTER
270
MPU TI 9900
FRONT PANEL DISPLAY CONTROLS
MAN II RCVR
274a
MAN II XMTR
276b
MANII XMTR
276a
140
400
TO RTU

Fig. 26

SPECIFICATION

Remote seismic data system

The invention relates generally to seismic exploration systems and, more particularly, to fiber optic seismic exploration systems.

In conventional seismic exploration systems, several hundred to a thousand seismic sensor groups, each composed of one or more individual sensors or geophones, are utilized to obtain seismic data. Usually a sensor group will contain one to thirty geophones electrically interconnected to form a single data channel. Conventional systems utilize a multiconductor seismic cable containing many conductor pairs, one pair for each sensor group, to transmit the seismic data from the sensor groups to a multichannel data processing and recording unit. As these conventional cables are extremely heavy and bulky, handling of such cables is very time consuming and, therefore, very expensive.

Recently, the use of fiber optics as a telemetry link for remotely distributed seismic systsms has been suggested, for example, see United States Patent No. 4,117,448 to Siems. Siems discloses a fiber optic cable with a set of triple-redundant optical fibers. The fibers are terminated at each end by a cable connector housing a light emitting diode (LED) and a photodetector. Siems suggests the transmission of digital data over the optical fibers. However, as the LED driver circuit and the photo-detector amplification circuit are housed within the remote seismic data gathering unit to which the connector is electrically connected, the digital data is not logic compatible. In other words, the signal amplitude of the digital data is much too low to interface directly with standard logic families, such as transistor-transistor logic (TTL), complementary metal-oxide semiconductor logic (CMOS), and emitter-coupled logic (ECL). Utilization of the arrangement disclosed in Siems is apparently not practical, as the digital data may become attenuated and distorted due to line capacitance, circuit loading and RFI/EMI pickup. Such effect results in costly inaccurate and unuseful data gathering.

It would be advantageous to provide a fiber optic seismic exploration system which has practical application in a field environment. It would also be advantageous to provide a fiber optic cable connector/transceiver which uses digital signal transmission to avoid irreparable attenuation and distortion of control and data signals. These useful results have been achieved by the present invention.

In accordance with the present invention, there is provided a seismic exploration system which includes a plurality of remote seismic data gathering units (RUs), a recorder takeout unit (RTU), and a central control unit (CCU). The RUs, RTU, and CCU are interconnected by fiber optic cables which are terminated on each end by a seismic cable connector housing a digital, logic compatible optical transceiver. The digital transceiver includes an optical detector and a fiber optic transmitter.

In a presently preferred embodiment, the fiber optic cable includes two optical fibers extending lengthwise through the cable and terminating in the connector/transceiver. One of the fibers is connected to the optical detector of the transceiver while the other fiber is connected to the fiber optic transmitter. Manchester II code is used to transmit data between the central control unit and the remote units. The recorder takeout unit is provided to transmit data to and from the remote units connected to either side of the RTU. The seismic system of the preferred embodiment transmits data in multiples of eight-bit groups, with each data word ending in a logic low level to conserve energy.

These and other advantages and features of the present invention will hereinafter appear, and for purposes of illustration but not of limitation, an exemplary embodiment of the present invention is shown in the appended drawings and described in the following detailed description.

FIGURE 1 is an isometric view of a seismic cable connector/transceiver, with the cover removed, in accordance with the present invention.

FIGURE 2A is an exploded view of the connector/transceiver of FIGURE 1 (without the cover).

FIGURE 2B is an enlarged cross-sectional view of the fiber optic cable which is used with the connector/transceiver of FIGURE 1.

FIGURE 3 is an electrical schematic of the fiber optic transmitter circuit which is used in the connector/transceiver of FIGURE 1.

FIGURE 4 is an electrical schematic of the optical detector circuit which is used in the connector/transceiver of FIGURE 1.

FIGURE 5A, 5B, and 5C are illustrative digital signal transmitted by the connector/transceiver of FIGURE 1.

FIGURE 6 is a mechanical schematic of a connector which is used in conjunction with the connector/transceiver of FIGURE 1.

FIGURES 7A-7E are block diagrams of seismic exploration systems employing the connector/transceiver of FIGURE 1.

FIGURE 8 is an illustrative view of a remote unit which is used in FIGURE 7.

FIGURE 9 is a block diagram of the circuitry of the remote unit of FIGURE 8.

FIGURES 10-24 are more detailed schematic diagrams of various components of the block diagram of FIGURE 9.

FIGURE 25 is a schematic diagram of the recorder takeout unit-central control unit interface shown in FIGURE 7A.

FIGURE 26 is a block diagram of the central control unit shown in FIGURE 7A.

Throughout the following description, similar reference numerals refer to similar elements in all figures of the drawings.

Referring to FIGURES 1 and 2, shown is a seismic cable connector/transceiver 10 in accordance with the present invention. The connector 10 has a shell or cover 12 which attaches to a mounting member 14. A rubber gasket 16 is provided to form an environmental seal between the member 14 and the cover 12.

A hollow rectangular member 18 is secured to the mounting member 14 for receiving one end of a fiber

optic cable 20. The members 14 and 18 may be a single integral piece. The cable 20 extends through a gland 22 which is environmentally connected to one end of the rectangular member 18 by a nut 24.

The fiber optic cable 20 has a jacket 26, preferably made of polyurethane, which surrounds two optical fibers 28. A buffer tube 30 surrounds each optical fiber 28 to aid in preventing the optical fibers from being damaged when they are looped or otherwise bent within the cable 20 or connector 10. A strength member 32 extends through the center of the cable 20 and is looped around an annular extension 34 secured to the mounting member 14. The strength member 32 is rigidly secured to the member 14 by a screw 36. The strength member may be a Kevlar fiber, an Arammid fiber, a high tensile strength plastic fiber, or the like and is provided to relieve tension from the fibers when external forces are applied to the cable.

Each end of the cable 20 also includes four twisted pair wires 38 for carrying the analog output signals of four sensor geophone groups, as more fully discussed below in connection with FIGURE 7. The four twisted pair wires 38 are soldered or otherwise connected to eight connections of a sixty-one pin electrical connector or plug 40, which is secured to the mounting member 14 at the end opposite the rectangular member 18. The electrical connector 40 may be of any conventional type such as that manufactured by Bendix. A filler material 42, such as Kevlar filler, is provided within the fiber optic cable 20. In the presently preferred embodiment, the twisted pair wires 38 and the buffer tubes 30 (containing the optical fibers 28) are helically wound around the strength member 32 to provide additional flexibility of the cable and to aid in relieving tension and compression forces on the fibers.

As shown, one of the optical fibers 28 is terminated in a fiber optic transmitter module 44 through a fiber optic connector 46. The fiber optic connector may be any conventional type, such as an Radiall Model No. F706.015.000, while the optical transmitter module 44 may be any conventional type such as Model No. SPX 4140 manufactured by Spectronics.

The second of the optical fibers 28 is terminated through a fiber optic connector 46 in an optical detector 48. Both the photodetector 48 and the optical transmitter 44 are mounted on a printed circuit board assembly (PCB) 50, which is secured to the mounting member 14. The PCB 50 contains transistor-transistor logic (TTL) circuits which activate the transceiver as more fully discussed below in connection with FIGURES 3 and 4. The PCB 50 is connected to the plug 40 by a plurality of wires (not shown), as discussed below.

When assembled, the cable connector/transceiver 10 provides an environmentally sealed optical cable connector which protects the transceiver and the ends of the optical fibers from being affected or damaged during field use. The connector is readily connectable to a remote seismic data gathering unit or box (FIGURE 7) via the plug 40. A lever or wrench 52 enables the connector 10 to be locked into place when plugged into a box.

Referring now to Figure 3, an electrical schematic diagram of the optical transmitter module is shown. The fiber optic transmitter 44 includes AND gate 62, acting as a buffer, connected to the base of an N-P-N transistor 64 over line 66. The emitter of transistor 64 is grounded through a resistor 68. The collector of transistor 64 is connected over line 70 to a light emitting diode (LED) 72. A pullup resistor 78 is provided to compensate for the parasitic capacitance created by the electrical connection to the remote unit (FIGURE 7).

In operation, the output of buffer 62 goes high, i.e., the output becomes a logic 1, when a digital signal appears on line 82, turning on transistor 64. The led 72 is energized and transmits light energy over one of the optical fibers.

Referring now to FIGURE 4, an electrical schematic diagram of the photodetector amplification circuit is depicted. A photodiode 88 is connected to a fiber optic receiver integrated circuit (IC) or preamplifier 90. The preamplifier 90 may be a Spectronics Model No. SPX 3620 or the equivalent. As light energy strikes photodiode 88, a bias current feeding into pin 1 of preamplifier 90 is modulated. The bias current is converted into a voltage signal within the preammplifier 90, and the voltage signal is compared to a threshold voltage level. When the threshold voltage is exceeded, a logic 1 appears at pin 12 of the preamplifier. The preamplifier IC contains an automatic gain control (AGC) circuit which gain ranges the voltage signal representative of the light energy striking the photodiode 88.

A voltage holding capacitor 96 is provided to establish the attack rate of the AGC voltage as required. An AGC override circuit 98 is provided to limit the AGC gain to levels which will not result in noise amplification sufficiently high enough to produce false logic outputs. A transistor 104 is switched on by a low level signal $\overline{\text{AGC Control}}$ at its base. This enables the AGC override 98 to affect the receiver 90 gain. The override is only enabled at times when no data in light form is present at the photodiode 88. Immediately upon receipt of valid data, the transistor 104 is switched off to allow the receiver 90 to gain range to the optimum level for proper data reception.

The output of the fiber optic receiver IC 90 (pin 12) is connected to a non-inverting input of a voltage comparator 120 through a high frequency filtering resistor 122. A symmetry restoration circuit 124 is connected to the inverting input of comparator 120. The symmetry restoration circuit is provided to restore the digital output of IC 90 which may be distorted by various system rise time versus full time differences and/or by pulse broadening effects of the optical fibers.

FIGURE 5A is an example of a digital signal as it should appear when transmitted from the connector/transceiver 10 to a remote unit (FIGURE 7) when unaffected by the aforementioned distortion effects. FIGURE 5B shows the digital signal as it would appear if affected by pulse broadening. The symmetry restoration circuit 124 restores the distorted digital signal to its original condition, as shown in FIGURE 5C. This is accomplished by a feedback loop which detects unsymmetrical data within the remote

unit, as more fully discussed below, and generates a correction voltage to be applied at TT6 (FIGURE 4).

Referring to FIGURE 6, shown is a mechanical schematic diagram of the plug 40. Lines 126 indicate the connections for the twisted pair wires 38 (FIGURE 2). Lines 128 correspond to the electrical connections between the plug 40 and various points in the circuits of FIGURES 3 and 4, as indicated by the alphanumerals.

FIGURE 7A is a block diagram of a fiber optic seismic exploration system 130 of the present invention. As shown, remote data acquisition units (RU) 132 and recorder takeout unit (RTU) 134 are interconnected through the dual fiber optical cables 20 by the connectors 10. The cables may have eight takeouts 136 for connecting an array of geophone groups 138. Utilization of the takeouts in the cables 20 is practical, as unwanted cross-over signals are not a problem in fiber optic cables. The recorder takeout unit 134 may be placed anywhere within the array of interconnected remote units. A central control unit (CCU) 140 is connected to the recorder takeout unit 134. The RTU serves as an input/output device for the CCU. It is a modified RU without analog circuitry but with additional transceiver support circuitry. The RTU reroutes the optical data from both directions to the CCU, allowing independent line operation in either direction.

FIGURES 7B-7E are block diagrams of alternate configurations of the seismic exploration system 130. In FIGURE 7B, an auxiliary array of geophone groups 142 is connected to some of the takeouts 136 in place of a portion of the standard array 138. Such configuration has application where more than one array type is needed to gather different seismic signal types. For example, the standard array 138 may record low frequency or p-wave data, and the auxiliary array 142 may be used for high frequency or shear-wave data.

FIGURE 7C is a configuration without cable takeouts on the data link cables 20. The geophone groups 138 are connected directly to remote units 132. Such a system may be desired when crossfeed between geophone inputs is of primary importance, and when other than in-line spreads are utilized.

FIGURE 7D represents a configuration with inputs from standard MIN-MAX* array 139, such as disclosed in U.S. Patent Nos. 4,024,492 and 4,151,504, which are incorporated herein by reference. MIN-MAX amplifiers 143 are provided between pairs of geophone groups and cable takeouts 136. FIGURE 7E typifies a MIN-MAX configuration in which the amplifiers are moved to the remote unit preamp inputs. It is to be understood that any desired configuration of geophone arrays may be utilized and still remain within the contemplation of the present invention.

*MIN-MAX is a trademark of Geosource Inc., the assignee of the present invention.

Shown in FIGURE 8 is a remote data acquisition unit or box 132. The remote unit or box has a detachable D-C power supply or battery pack 142 for powering the electronics within the box 132 and within the connectors 10 which are connected to that box. Four sixty-one pin male connectors 144, two each on opposite sides of the box, are provided. Two of the four connectors, one on each side of the box, are mated with plug 40 of the connector/transceiver 10. The other two connectors 144 are provided as an alternate connection for geophone groups 138. Rather than connecting the geophone groups to the takeouts 136 in the cables 20, the geophone groups may be connected directly to the boxes 132, as previously discussed in connection with FIGURE 7C. The box 132 is constructed of structural foam, thereby considerably reducing the weight of the box.

Each remote unit contains the necessary circuitary to preamplify, filter, gain range, and digitize the analog inputs from the geophone groups. Referring to FIGURE 9, shown is a block diagram of the circuitry of remote unit 132. As shown, eight analog inputs, four from each of two standard or alternative connectors 144, are fed over lines 150 to multiplexer 152, which selects either standard or alternate inputs. The analog inputs are filtered for high frequency and amplified in quad preamps 154 prior to being input into track-and-hold, instantaneous floating point (IFP), and analog-to-digital (A/D) module 156. All analog input signals are sampled simultaneously by the track and hold network, and are gain-ranged from 1 to 32,768 times to near A/D midscale by the IFP, as disclosed in U.S. Patent Nos. 4,104,596 and 4,158,819, which are incorporated herein by reference. The resulting digitized mantissa and gain words for each original input or channel are fed to output formatter 158, which loads the parallel data into a serial output buffer for transmission via optical link 20 to CCU 140.

Timing and control unit 160 functions as a controller for the entire remote unit. It receives and decodes control data from the CCU through receivers 162 to initiate the sampling and digitization process. All channels are sampled simultaneously, gain-ranged, and digitized according to the control logic sequence. At the appropriate time, the timing and control logic provides digital data to transmitters 164 for transmission to CCU 140. Control pulses received from the CCU contain an operation code, a group of five bits which the timing and control unit decodes into RU setup parameter, such as relay selection, K gain, filter selection, function generator control, etc.

Power supply board 166 utilizes battery pack 142 to develop regulated voltage supplies via DC-to-DC converters. Power on/off interlock 168 is provided to enable remote unit power-up and operation when one or more cable connectors 10 are engaged, as more fully discussed below. Buzzer 167 is provided pramarily for theft protection; however, it also provides indication of faulty operating conditions. Shown in FIGURE 10 is the buzzer alarm logic. Signal CONNECTORS ON is generated when either of the two connector/transceivers is attached to the RU. The signal CONNECTORS ON clocks one-shot 300 which momentarily activates the buzzer, indicating that battery pack 142 is not dead.

Unauthorized disconnect register 302 and unauthorised power down register 304 are enabled whenever the RU is powered up. The reset of these registers is controlled by the CCU. When both con-

nectors are removed, signal CONNECTORS OFF goes high. If authorized disconnect register 302 is set when signal CONNECTORS OFF goes high, AND-gate 306 is triggered, thereby energizing the buzzer. This theft protection is operable with the RU powered up or powered down. When communication to the CCU is interrupted, signal POWER DOWN goes high. If unauthorized power down register 304 is set when signal POWER DOWN goes high, flip-flop 308 and AND-gate 310 are activated, thereby energizing the buzzer.

The buzzer may also be enabled by an external voltage check circuit (not shown).

Referring now to FIGURES 11A and 11B, shown is a block diagram of a single channel of quad preamp/filter 154. When test relay 170 is enabled to the external inputs position (as shown), geophone analog input signals are fed into preamp or K Gain stage 172. K Gain stage 172 may be remotely programmed to gains of 4, 16, 64, or 256 by register 174. Low-cut prefilter 176 receives the output from preamp 172 and serves to low-pass filter the signal prior to its input into switched low-cut filter 178. Low-cut filter 178 may be configured as a O (OUT), 12, 24, or 36 dB per octave high-pass filter by proper stage selection with switches 180 and 182, which are set by register 184. Low-cut corner frequency is determined by the duty cycle of low-cut frequency clocks 186, as more fully discussed below in connection with FIGURE 12.

Low-cut filter 178 is followed by 50 or 60 Hz strappable notch filter 188 which is remotely selectable as either "in" or "out" with switch 190. Notch filter 188 consists of two cascaded second order notch filters to provide better than 60 dB attenuation over a 0.2 Hz bandwidth.

Seventh order switched elliptical anti-aliasing filter 192 follows notch filter 188. The corner frequency is remotely selected by the duty cycle of alias frequency clock 194, as discussed more fully below in connection with FIGURE 12, at one of ten frequencies in two frequency bands of 44 to 500 Hz (standard) or 62.5 to 714 Hz (optional). The standard slope is 96 dB/octave MAX while the optional slope is 76 dB/octave.

Anti-aliasing filter 192 is followed by post-aliasing filter 196 which removes switching transients from the signal. The output of filter 196 is AC-coupled into gain stage 198 which functions as an output buffer and gain-adjust mechanism. The output is then switched to the track-and-hold (FIGURE 13) by control logic 222 using switch 200.

Low-cut filter 178 and anti-aliasing filter 192 use pulse width controlled signals for controlling filter corner frequencies. Shown in FIGURE 12 is a schematic diagram of the switched filter control circuit 232 which generates the necessary clock pulses and provides the CCU interface for pulse width control. This circuit also synchronizes the filter switching with the control clock, thereby minimizing the transient signal noise received by the track-and-hold.

Clock circuit 312 generates a 640 KHz or 320 KHz clock signal, depending on whether anti-alias filter 192 corner frequency is set above or below 250 Hz (by command word data). The clock signal is divided by 80 in counter 314 to yield an 8 KHz or 4 KHz period for filter control. The 8 KHz/4 KHz signal is used as a reset signal for counters 316 and 318 and latches 320 and 322. Counters 316 and 318 control the pulse width of the filter control signals by setting latches 320 and 322, respectively, at a time determined by command word data. The end result is that the filter switching control period is controlled by the antialias corner frequency which selects either an 8 KHz or 4 KHz reset cycle. The pulse widths of the filter control signals, which correspond to the respective duty cycles, are determined by the values loaded into registers 324 and 326 (which preset counters 316 and 318, respectively) by a CCU command word over line 328.

In the presently preferred embodiment, there are four preamps/filters per card, along with associated data registers and support circuitry. Two quad preamp cards 154 are provided in each box 132; however, control logic 160 can accommodate a single card.

FIGURE 13 is a block diagram of track-and-hold, IFP, and A/D module 156. Each preamp 154 output is fed into a corresponding track-and-hold (T/H) 202a-202h (a total of eight) prior to reception of a command word from CCU 140. When the command is detected, T/H 202a-202h are simultaneously switched from the tracking mode to the hold mode, thereby providing minimum sampling skew.

According to the established box direction and sampling rate, successive channels are multiplexed by MUX switch 206 to IFP gain-ranging amplifier 208. MUX control is provided by channel address counter 210. The basic purpose of IFP amplifier 208 is to amplify the analog input signals to a value near the full-scale range of A/D convertor 212, usually between one-half and full scale, and to provide a digital code corresponding to the actual gain applied to the input signal.

The signal is held constant during the gain-ranging process. This process uses a successive approximation logic sequence to apply appropriate IFP gain stages 208 to amplify the hold sample by the necessary gain 2^n, where $n = 0, 1, 2, \ldots, 15$. Level detector 214 is enabled at the end of each IFP gain-stage time cycle. The amplified signal is then sampled by A/D track-and-hold 216 and converted to digital data by A/D converter 212 for transmission along with the gain code generated during the gain-ranging process.

To prevent various stages of IFP amplifier 208 from introducing significant offset errors, a correction voltage is subtracted from each stage. Periodically, the offset of each IFP stage is detected by offset logic 218, and the correction voltage is incremented by a small amount in a direction that will reduce the offset.

MUX average 220 is used to correct preamp offset errors prior to gain stage amplification. Each channel's error correction voltage is summed into its held signal to cancel the offset during its MUX time. The correction signals are updated each scan time.

Control logic 222 provides the timing and control for T/H, IFP, and A/D module 156. This logic controls the T/H MUX timing, IFP gain stage switching, A/D

converting, and data register storing.

System size is input from RU timing and control logic 160 (FIGURE 9) to channel address counter 210. Four or eight channels are selected, based on the desired field spread and scan rate. When channel selection other than four or eight is required, data is still multiplexed to IFP amplifier 208 as four or eight channels, but unnecessary data is stripped before transmission to data link 20 by output formatter 158.

As shown in FIGURE 14, mask control logic 329, which is included in logic 160, controls the digitized analog data to be formatted and transmitted to the CCU. Control is achieved by the CCU loading a mask bit for each channel, which enables the selection of specific channels for data input to the CCU. Two 8-bit registers 330 and 332 are provided so that dynamic sampling may be achieved. As only one register is used at a time, the other register may receive updated mask bits. The transition between registers 330 and 332 is controlled by the CCU.

Each analog channel is dedicated to a particular geophone group, and one of eight different MUX address codes 000, 001, 010, . . . , 111 is dedicated to each channel. Whenever data is available from any one channel, its address code is presented to multiplexer 334. Multiplexer 334 selects the corresponding mask bit for that channel and presents it to output formatter 158 (FIGURE 15). A "1" mask bit allows the formatter to convert channel data for transmission; a "0" causes the formatter to ignore this channel.

Referring to FIGURE 15, shown is a block diagram of the remote unit timing and control logic 160. Box "power on" control interlock 168 cycles power to optical receivers 48 (FIGURE 2) in connector/transceiver 10 until transmission is detected, at which time main power supply 166 (FIGURE 9) is enabled. If no optical reception occurs for a specified period of time, "power on" circuitry 168 senses the inactivity and returns to the cyclic power on/off mode.

Because connectors 10 are mechanically identical, box direction/box on line control circuit 224 is provided. Circuit 224 determines the direction of incidence of the first (command) signal and establishes this as the CCU direction. With this information, the remote unit may be set up for proper preamp multiplexing regardless of connector interchange.

Each powered-up RU begins in a repeater mode. As shown in FIGURE 16, after a command word (CW) transmitted by the CCU passes through a RU, signal CW RECEIVED clocks box-on-line flip-flop 336, which switches out receiver lines 338 and connects RU data formatter/encoder 158 and end-of-transmission (EOT) generator 230 (FIGURE 15) to appropriate optical transmitters. The RU has now been taken out of the repeater mode and is awaiting receipt of the EOT signal from the previous upstream RU. After detecting this EOT signal (which is blocked from passing through), the RU transmits its encoded data upstream to the CCU. Thus, the data from this RU is inserted behind the data from the previous RU. By controlling when the EOT is transmitted from the previous RU, the gap between the two data bursts is controlled.

After the encoded data has been transmitted to the CCU, the RU transmits an EOT signal to the next downstream RU. At this time, signal, DATA TRANSMITTED clocks flip-flop 336, which disconnects formatter/encoder 158 and EOT generator 230 and places the RU back in the repeater mode.

To ensure that the entire command word has been received by the RU, the RU remains in the repeater mode for a time period of preferably nine microseconds after signal CW RECEIVED is generated. This time period is longer than the time required to receive a command word, but shorter than the time lag between the generation of signal CW RECEIVED and the EOT signal.

Manchester II decoder and serial-to-parallel conversion logic 226 (FIGURE 15) functions as an input decoder and data formatter. Manchester II code (Man II code) is utilized because of its "self-clocking" asynchronous format. All transmissions are burst mode Man II code to conserve power. As shown in FIGURES 17A and 17B, logic 226 decodes the incoming signal and stores it in a parallel register for output to command word decoder 228.

As shown, a Manchester II clock pulse (Man II ck) is generated by EXCLUSIVE OR-gate 340 and inverter 342 each time a transition occurs in the Man II code. The Man II ck clocks one-shot 344 which has a time constant of 3/4 bit cell time. The Man II ck also clocks J/K flip-flop 346, with the 3/4 bit cell time tied to the J input. The Q output of flip-flop 346 is Manchester II data (representative of either seismic data being transmitted upstream or command data being transmitted downstream). If a Man II ck occurs during the 3/4 bit cell time, the Q output of flip-flop 340 goes high, indicating that the Man II data is a "1". The 3/4 bit cell time also clocks the Man II data into a 33-bit serial-to-parallel shift register 348. If a Man II ck occurs during the 3/4 bit cell time, a "1" is loaded into register 348. Otherwise, a "0" is clocked into register 348.

A preamble of all zeros precedes a command word. As a result of repeated transmission, the leading bits of the preamble may become distorted and decoded as a "1". To prevent false 1's from being detected, preamble stripper logic 350 is utilized. When the preamble is received, the first transition of Man II code causes flip-flop 352 to go high. This high output is delayed by strip time RC time constant circuit 354, preferably two microseconds. After the time delay, one-shot 344 is allowed to fire. Flip-flop 352 is reset after all CW data is received. Command word decoder 228 decodes the parallel command word into the following:

1. Preamble – a 24 to 56 bit all "0's" data train used by optical receiver symmetry restoration circuitry 124 (FIGURE 4) to maintain input data integrity. RU logic effectively ignores this segment of the command word;

2. Sync Code – a two-bit sequence signifying decoder start;

3. RU Address – a nine-bit code unique to each RU. RU logic ignores all codes except all "1's" and its box address. Addresses are assigned during the RU power-up sequence;

4. OP Code – a five-bit code defining the operation to be performed. For example, a box address assignment has Op Code 00000;

5. Data Word – a fifteen-bit code which is loaded into registers for preamp control box set-up (mask), function generator, etc.;

6. Stop Bit – a one-bit code, a "1" used as a data validity check bit, indicates that the data is good;

7. Delay – a calculated N bit data delay which allows each RU to dump its data onto the optical link before receiving additional data from the adjacent RU; and

8. EOT – a four-bit code which signifies end-of-transmission of the command word and the start of data output to the CCU.

As stated above, the command word includes a nine-bit code which is used to give each RU an individual identity in order to keep its data separate. As shown in FIGURE 18, nine-bit register 374 is provided in each RU, affording 512 possible different combinations. Comparator 376 is included to identify any CW box address that matches the data in register 374. All 1's detector 378 is provided to detect an all 1's address code.

When the RU powers up, register 374 is cleared so that the box address is "000000000." A special command word transmitted by the CCU assigns a binary number between one and 510 to the RU, as determined by the relative position of this RU with respect to the CCU and the other RUs, which is loaded in to register 374. The numbers one through 510 are used as individual box addresses. An all zeros address code is used only during powering up, while an all ones code is used to enable the CCU to communicate with all of the RUs at the same time.

End-of-transmission detector generator 230 (FIGURE 15) determines when an EOT code is sent to the next RU so that the latter can transmit its data. As shown in FIGURES 19A and 19B, two individual EOT circuits control the transmission of data from the RUs. One detects the EOT transmitted from the previous upstream RU; the second generates an EOT code for transmission to the next downstream RU.

The EOT detector of FIGURE 19A includes counter 356 which is resset and enabled when a command word is received. Counter 356 is disabled after the EOT code is received. The command word (CW) precedes the EOT code in the data stream. The time delay between them depends on the quantity of data transmitted by each RU and the position of the particular RU in the line. The more RUs between this RU and the CCU, the longer the delay between the CW and the EOT. The EOT code clocks counter 356, thereby triggering formatter/encoder 158 (FIGURE 15) to begin data transmission.

The EOT generator of FIGURE 19B is partially controlled by the CCU. Typically, EOT transmission is completed approximately one microsecond after data transmission is completed. The CCU can change this time differential or gap by modifying the code loaded into register 358. A different code addresses another section of programmable read-only memory (PROM 360, producing a different EOT position with respect to transmitted data (that is, changing the gap).

Counter 362 counts the number of digitized analog channels which are to be transmitted. Counter 362 addresses PROM 360, and the output of PROM 360 presets counter 364. As data is transmitted, counter 362 begins counting, and the output from the counter allows the EOT code to be transmitted at the correct time.

Preamp control logic 232, as discussed above in connection with FIGURE 15, determines the frequencies and duty cycles of the low-cut and anti-alias switched filter clocks 186 and 194 (FIGURE 11) and decodes and enables all other preamp setup and control functions defined in the preamp block diagram (FIGURE 11).

Blast command circuit 234 is provided to initiate a contact closure which activates an energy source. As shown in FIGURE 20, the circuit is first armed, and then a "fire" command is issued to cause the contact closure. The fire command must be issued within one second after arming, or the circuit is automatically disabled. The "arm" command is a logic low signal on line 366 (received from the CCU) that resets timer 368, thereby removing the reset from flip-flop 370. When a logic high signal is received on line 366 (indicative of a fire command), flip-flop 370 is clocked to a logic "1," and transistor 372 is turned on, causing the contact closure to the energy source control located outside the RU.

FIGURE 21 is a block diagram of output formatter/encoder 158. In the presently preferred embodiment, a standard set of output data for each channel includes a four-bit gain word and a fifteen-bit data word. Output data from each remote unit is formatted into a sequence of words as follows: (1) a two-bit sync code; (2) a one-bit box fault code; (3) a nine-bit RU address; and (4) one to eight sets of channel data. The total word length is selected to obtain a "0" logic level at the end of transmission to conserve power between transmissions and to utilize eight-bit groups to simplify encoding. The following chart indicates the nine possible word lengths which may be transmitted from a RU, depending upon the number of channels being transmitted:

	OUTPUT DATA	NO. OF BITS TRANSMITTED
SYNC + FAULT + ADDRESS +	0 Channels = 12 BITS	16
SYNC + FAULT + ADDRESS +	1 Channel = 31 BITS	32
SYNC + FAULT + ADDRESS +	2 Channels = 50 BITS	56
SYNC + FAULT + ADDRESS +	3 Channels = 69 BITS	72
SYNC + FAULT + ADDRESS +	4 Channels = 88 BITS	88
SYNC + FAULT + ADDRESS +	5 Channels = 107 BITS	112
SYNC + FAULT + ADDRESS +	6 Channels = 126 BITS	128
SYNC + FAULT + ADDRESS +	7 Channels = 145 BITS	152
SYNC + FAULT + ADDRESS +	8 Channels = 164 BITS	168

It is to be understood that the data output may have other formats and still remain within the scope of the present invention.

As shown in FIGURE 21, the formatter circuit includes counter 380 to count the number of channels formatted, PROM 382 to determine how many bits need to be shifted (based on the above chart), counter 384 to count how many shifts have occurred, and first-in, first-out (FIFO) memories 386 to store the formatted data until transmission. When the command word is received, the sync bits, fault bits, and box address are loaded into shift register 388. Simultaneously, the required number of bits to be transmitted are transferred from PROM 382 to counter 384. As shift register 388 shifts, counter 384 counts. After eight bits are shifted and presented to memory 386, a clock is generated to load the eight bits into memory. This process continues until all full eight-bit words are transferred into FIFO memory, at which time counter 380 increments its count. Any left-over bits remaining in the shift register are used to complete the next eight-bit word. Two FIFO memories are provided so that one may be loaded with new data as the other is unloading data to the encoder circuit.

The encoder circuit generates the preamble, accepts and serializes eight-bit words from memories 386, and converts this serial data to Manchester II code. When an EOT code is received from the previous RU, a preamble of specified length (similar to the command word preamble) is generated, after which an eight-bit data word from memories 386 is transferred to shift register 390. The first word transferred is the sync bits, the fault bit, and part of the box address. Register 390 shifts at an 8 MHz rate into Man II coder 392 which generates the bit cell transitions. FIFO memories 386 unload at a 1 MHz rate which matches the 8 MHz shift rate so that there is a continuous data stream out of Man II coder 392. Encoding stops when a signal from FIFO memory indicates it is empty. The final bit coded causes the output of Man II coder 392 to be at a logic low level.

Referring to FIGURE 22, Man II coder 392 is enabled by taking the input to AND-gate 394 high. During generation of the preamble, register 390 is cleared, causing all zeros data to be presented to coder 392. OR-gate 396 causes J/K flip-flop 398 to toggle at bit cell times. Once generation of the preamble is completed, memory data is loaded into register 390. As the data shifts out, flip-flop 398 either changes state at mid-cell time when a "1" is presented to coder 392 or remains in its present state because a "0" is presented. After all data is coded, Man II coder is disabled by taking the input to AND-gate 394 low.

A block diagram of function generator 169 (FIGURE 9) is shown in FIGURE 23. Test signals are generated sample by sample in digital form by the CCU. This digital signal is then transmitted to the remote units in the command word. In the remote units, the digital signal is converted to an analog signal with a near full-scale peak value by digital-to-analog (D/A) converter 240. The resulting analog signal is attenuated to the desired amplitude by digitally controlled attenuators 242 and 244. The low level analog signal is then fed into preamp oscillator inputs 201 for test purposes.

FIGURE 24 is a block diagram of battery pack 142 and power supply 166. The battery pack includes two 12 volt lead-acid batteries connected in series with a common output. When a connector/transceiver is engaged with a remote unit connector 144, interlock circuitry 168 is enabled. Optical receivers 48 are cycled on and off to conserve power until light transmission is detected. Signal VREG ENB then goes high to force power on/off control 246 to enable soft-start circuitry 248 and main power relay 250. Power is distributed to two DC-to-DC converters 252 and 254. Resulting outputs are filtered with high-cut filters 256, 258, and 260 prior to distribution for various box functions. Secondary relay 262 must be thrown to enable power to function generator 169.

The recorder takeout unit (RTU) is provided as an auxiliary interface between the CCU and the RUs. The RTU regenerates Manchester II code being transmitted to and from the CCU. This regeneration is performed with high speed clocks and circuits to reduce bit jitter, allowing lengthy interconnecting cables to the CCU. The RTU is unnecessary if the distance between the spread and the CCU is relatively short, such as less than 400 feet.

As shown in FIGURE 25, the RTU is connected to the CCU through input/output panel 400 (located in a track carrying the CCU). Input panel 400 is the link between electronics inside the truck and electronics outside the truck. Manchester II code is transmitted between the RUs and the input panel via fiber optics, but the input panel is connected to the CCU by twisted pair wires. Two fiber optic cables (only one is shown) are connected between the RTU and the input/output panel. One cable is dedicated to transmitting data between the CCU and the RUs disposed to the left of the RTU while the other cable

is dedicated to transmitting data between the CCU and RUs disposed to the right of the RTU. It is to be understood that the spread of remote units may be optically connected to the central control unit via the input/output, such as when the CCU is within 400 feet of the spread, and still remain within the contemplation of the present invention.

Referring now to FIGURE 26, shown is a block diagram of CCU 140 and associated equipment. Microprocessor unit (MPU) 270 serves as the main controller for the system. Input/output truck panel 400 is provided, as discussed above, to interface RTU 134 with Manchester II receivers 274 and Manchester II transmitters 276. Transmitters 276 accept command words from the MPU and convert them to serial data with Manchester II encoding for subsequent transmission to the remote units. Receivers 274 accept asynchronous data input from the remote units and decode the data. Receivers 274 also check for parity errors, i.e., transmission faults.

Formatter 278 formats the seismic data into a standdard multiplexed format, writes this data into buffer memory 280, and decodes the data words requested by MPU 270 by RU address number. The data formatting is complicated by allowances for dynamic sampling which results in some data being stripped out of the data stream, as previously discussed.

Buffer memory 280 is an interleaved set of two 1K x 20 random accessory memory units (RAMs) which contains buffers for the seismic data and gain words. The buffer memory compensates for the unsynchronized input/output of the CCU with respect to digital unit 282. This data along with header information 284 is transferred synchronously to the digial unit. Digital unit 282 includes a recorder, tape transport 284, and various auxiliary devices.

MPU 270 performs the following tasks:

1. A status table is used to store frequently used line parameters, such as preamp setting, box number, system size, etc. At system set-up time, the MPU controls the output of this data to the remote units.

2. The MPU formats the front panel display, decodes and registers the front panel switches, and converts the binary data into decimal form.

3. The MPU controls the roll-along operation of the remote units to allow automatic move-up, gap size, etc.

4. The MPU utilizes stored programs to set up, run, and analyze various Go/No Go tests for the system as well as system performance tests.

5. The MPU organizes data input/output and timing during the recording process.

The CCU encodes the command word by the same method as the Manchester II coder, except that the command word is coded and transmitted at a 4MHz rate. The commands to be coded are generated by software. When no communication is required with the RUs, a command word must be sent to keep the RUs powered up so that they may acquire data for transmittal to the CCU. A command word of all zeros except for a "1" in the sync code is used for this purpose.

The CCU decodes the Manchester II code in a manner similar to that of the RUs, using edge clocks, 3/4 bit cell times, and shift registers (not shown). While all command words that are decoded by the RUs are 32 bits long, data transmitted to the CCU for decoding may be 16 to 168 bits long, as previously discussed. To accommodate these different word lengths, a counter and a PROM decoder (not shown) are used to determine when data is available in the shift registers. Two holding registers, one used for the box address and the second used for the seismic data, are used in conjunction with a third shift register to hold incoming data to be transferred to buffer memory 280 while additional data is being loaded into the third register. A channel counter (not shown) is also provided to keep track of the number of channels. The box address, the channel number, and the recording tape format determine the location in the buffer memory in which the data is written. The box address and channel number are also used as an address for map memory 402 which is a random-access-memory (RAM) element. The contents of RAM 402 are used to address buffer memory 280. Buffer memory 280 is divided into two sections, and each section is alternatively loaded and unloaded during each scan. RAM 402 addresses (loads) one section of buffer memory 280 while digital unit 282 addresses (unloads) the other section.

The contents of RAM 402 are generated by MPU 270 from information supplied by the operator and stored in the status table. Any RU seismic data, therefore, may be placed in any necessary location in buffer memory 280.

Certain verification checks are performed on incoming RU data. First, the number of bits received from each RU is checked to verify that it was correct. Second, the fault bit is checked to determine if it is set. Third, the box address is checked to make sure it is being received in sequential order. If any of these checks detect faults, the box address of the RU along with the type of error detected is loaded into a memory and a flag is set. MPU 270 scans these flags periodically and notifies the operator when a flag occurs.

There are also checks performed on the seismic data as it passes through buffer memory 270. A parity check is made to determine bad memories, and a full scale check is performed on the seismic data to indicate an overload condition. Any detected faults are loaded into a memory, and a flag is set for the MPU.

Auxiliary channels 404 are provided in the CCU for a variety of purposes known to those skilled in the art, such as time break verification. The data is stored in an auxiliary buffer memory (not shown) and then transferred to buffer memory 280 at the appropriate time. A counter (not shown) addresses an auxiliary RAM memory (not shown) as each channel is transferred. Auxiliary channel data may be stored in any location as needed, like the RU channel data.

In operation, a digital command signal may be transmitted from the central control unit 140 to the recorder takeout unit 134 (FIGURE 7A). The recorder takeout unit then transmits the digital signal to all the remote units by utilizing the digital connec-

tor/transceiver 10 of the present invention. The digital signal is electrically transmitted to the transceivers within the connectors 10d and 10e. The digital signal is converted into light energy by the fiber optic transmitter 44 within each connector. The light energy representing the digital command signal is then transmitted to the adjacent transceivers 10c and 10f, respectively, over one of the optical fibers 28 in the cables 20. The light energy is detected by photodiodes 88 within the connectors 10c and 10f. The light signal is transformed back into a digital signal, which is electrically transmitted to the remote units 132b and 132c. The remote units then sense the digital command signal to see if it applies to them and electrically transmit the digital signals to the connector/transceivers 10b and 10g. The optical fiber transmitters 44 within the connectors 10b and 10g convert the digital command signal into light energy which is transmitted to the next adjacent connector/transceivers 10a and 10h, respectively, through the cables 20. The process is then repeated.

Regarding data transmission, the analog output signals of the geophone groups 138 are transmitted to the remote units 132 over the twisted pair wires 38 which are connected to the takeouts 136. In operation, seismic analog data is received by remote unit 132B, for example. Remote unit 132B transforms the analog data into digital data, which is then electrically transmitted to connector/transceiver 10c. The digital data is transformed into light energy by the optical transmitter 44 in connector 10c. The data is optically transmitted over cable 20b to connector/transceiver 10d, where it is received by photodetector 48. The photodetector transforms the optical data back into its digital electrical state and transmits the digital data to the recorder takeout unit 134.

As the remote seismic data system is nonpolarized, it does not matter which end of the cable 20 is connected to a remote unit. Once a cable is interconnected between two remote units, one of the optical fibers will only carry digitized command signals while the other fiber will only carry digitized seismic data signals. The cable 20 may carry command data and seismic data (in opposite directions) simultaneously, thereby operating as a digital full duplex system. However, the presently preferred embodiment incorporates half duplex mode operation to preserve signal-to-noise performance.

It is to be understood that the invention will admit of other embodiments, such as a system using a single fiber bi-directional data link. The description of the preferred embodiment is given only to facilitate understanding of the invention by those skilled in the art and should not be construed as limiting the invention.

CLAIMS

1. A fiber optic seismic exploration system, characterized in that the system comprises:
a plurality of remote seismic data gathering units;
a central control unit;
a plurality of fiber optic cables, including a duplex optical link, for interconnecting adjacent remote units and the central control unit; and
a seismic cable connector having a digital, logic compatible optical transceiver connected to each end of the cable for mating the cable to the remote units and the central control unit.

2. The system according to claim 1, characterized in that an input/output panel interfaces the central control unit with the remote units, the input/output panel being optically linked to the remote units and being electrically connected to the central control unit.

3. The system accoding to claims 1 or 2, characterized in that a recorder takeout unit is disposed between any two adjacent remote units, the recorder takeout unit being a modified remote unit for regenerating digitized data to and from the remote units, the recorder takeout unit being optically linked to the central control unit.

4. The system according to claims 2 or 3, characterized in that the input/output panel and the central control unit are disposed in a mobile vehicle.

5. The system according to any of claims 1-4, characterized in that each remote unit includes connector-on circuitry for momentarily enabling an audible signal when a cable connector is connected to a remote unit with normal battery voltage.

6. The system according to any of claims 1-5, characterized in that each remote unit includes power down circuitry for enabling an audible alarm when communication with the central control unit is unintentionally interrupted.

7. The system according to any of claims 1-6, characterized in that each remote unit includes unauthoriszed disconnect circuitry for enabling an audible alarm when both cable connectors are removed.

8. The system according to any of claims 1-7, characterized in that burst mode Manchester II code is used to transmit data between the central control unit and the remote units.

9. The system according to any of claims 1-8, characterized in that data is transmitted in multiples of eight-bit groups.

10. The system according to any of claims 1-9, characterized in that each data burst ends in a logic low level to conserve energy in transmission.

11. The system according to any of claims 1-10, characterized in that each remote unit is assigned a box address by the central control unit.

12. The system according to any of claims 1-11, characterized in that an end-of-transmission code is transmitted by the central control unit and each remote unit after a predetermined time delay following data transmission.

13. The system according to claim 1-12, characterized in that each remote unit is in a repeater mode until an end-of-transmission code is received.

14. The system according to any of claims 1-13, characterized in that command data transmitted from the central control unit comprises a multi-bit word including a sync code, a box address code, an operation code, a box set-up code, and a stop code.

15. The system according to any of claims 1-14, characterized in that each remote unit gathers up to at least four channels of seismic data, the seismic data being transmitted in different word lengths of multiples of eight bits depending upon the number of data channels enabled, each data channel including

a multi-bit code comprising data, each word including a sync code, a fault code, and a box address code.

16. The system according to any of claims 1-15, characterized in that each remote unit includes mask control circuitry for selecting which of the available data channels is to be transmitted.

17. The system according to any of claims 1-16, characterized in that a preamble of all zero bits precedes command data to provide data integrity and wherein each remote unit includes preamble stripper circuitry to prevent false data from being detected.

18. The system according to any of claims 1-17, characterized in that a preamble of all zero bits precedes seismic data to provide data integrity and wherein the central control unit includes preamble stripper circuitry to prevent false data from being detected.

19. The system according to any of claims 1-18, characterized in that each remote unit comprises circuitry to preamplify, filter, gain range, and digitize analog seismic data.

20. The system according to claim 19, characterized in that the filtering circuitry comprises switched filters which use a pulse width controlled signal for filter cutoff point control, the pulse width being set by the central control unit, the filter switching being synchronized with a control clock to minimize switching transients.

21. The system according to any of claims 1-20, characterized in that the central control unit includes circuitry for performing parity checks, full scale checks, bit count checks, fault bit checks, and box sequence checks.

22. A method for use with the system of any of claims 1-21 for gathering seismic data in a seismic exploration system, characterized in that the method comprises the steps of:

receiving light energy representative of a digital, logic compatible signal in a seismic cable connectors;

transforming the light energy into the digital, logic compatible signal within the connector; and

electrically transmitting said digital signal to an adjacent remote seismic data gathering unit.

23. The method according to claim 22, characterized in that the method further comprises the steps of:

simultaneously receiving a digital, logic compatible signal in a seismic cable connector;

transforming said digital signal into light energy within the connector; and

optically transmitting the light energy through a fiber optic cable.

24. A fiber optic seismic exploration system, substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

25. A method of seismic exploration substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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